GeothermEx, Inc. 901 MENDOCINO AVE.
BERKELEY, CA. 94707

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

GEOLOGY, GEOCHEMISTRY AND EVALUATION OF PROPOSED GRADIENT HOLE SITES, CLEVELAND-MAPLE GROVE PROSPECT, CARIBOU AND FRANKLIN COUNTIES, IDAHO

for

SUNOCO ENERGY DEVELOPMENT CO.
DALLAS, TEXAS

by

GeothermEx, Inc.

J. R. McIntyre
C. W. Klein
B. L. Cox

June 1980

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DISCLAIMER

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July 8, 1980

Mr. John Knox
Sunoco Energy Development Co.
12700 Park Central Place
Suite 1500
Dallas, TX 75251

Dear Mr. Knox:

It has come to our attention that several errors were made during the typing of the Cleveland-Maple Grove report submitted to you in June. Please find enclosed two corrected copies of pages 2, 7, 9, 14. Also included is a copy of each page with the corrected word circled. These new pages should be substituted in the report for the present pages.

I apologize for any inconvenience this may have caused you.

Sincerely,

Gloria M. Wilson

Gloria M. Wilson

GMW:wy

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GEOLOGY

Geologic Setting

The prospect area is located at the eastern edge of the Late Precambrian to Early Mesozoic Cordilleran geosyncline, adjacent to the Wyoming-Utah foreland. The oldest rocks in the geosyncline are amphibolite, schist, gneiss and granite. These are overlain by 15,000 to 25,000 feet of Proterozoic metasedimentary and minor metavolcanic rocks of greenschist metamorphic grade. The Late Precambrian rocks are apparently absent from the foreland area, indicating that the distinction between the shelf and the geosyncline was already established before the beginning of Cambrian deposition.

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By Middle Jurassic time, much of the old geosyncline was being uplifted and the axes of deposition had begun a progressive shift to the east, across the hinge-line onto the former shelf. This shift culminated during Cretaceous time, in the folding of the Paleozoic-Early Mesozoic geosynclinal rocks and the development of major overthrust zones in which the geosynclinal rocks were displaced to the east, over the shelf margin. The project area is located on the western side, and in the hanging wall of the Bannock thrust, one of the major thrust faults of the region.

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Tufa deposits of impressive volume occur around active and fossil thermal mineral spring sites at Maple Grove, Cleveland, McGregor Ranch (from the center of the south half of Section 30 to the south line of Section 31, T. 12 S., R. 41 E.) and at the large mound centered in the southeast quarter of Section 13, T. 12 S., R. 40 E. Additional small deposits have been reported at unspecified localities on Williams Creek and along the west side of the valley in the vicinity of the so-called Hale Mine (northeast quarter of Section 23, T. 12 S., R. 40 E.) (Bright, 1960). These deposits are an indication of the potential extent of the deep thermal mineral water system which may exist in the area.

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Manganese-depositing hot springs are known in several other parts of the region, among them Lava Hot Springs, Idaho, and Abraham Hot Springs, in Utah. In discussing deposits of this type, Hewett and Fleisher (1960) conclude that the waters originate at great depth but they do not specifically propose an igneous origin for any of the components.

Hydrology

The main topographic elements in the hydrologic framework of the study area are the Gentile Valley-Mound Valley depression, flanked on the west and south by the Portneuf Range and on the east by the Bear River Range. The area also includes the northern end of Cache Valley, south of the Treasureton Pass segment of the Portneuf

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The deep-circulating part of this system is that which is of significance to geothermal occurrences. Most of the known geothermal systems in the Basin and Range province are related to the major deepseated fault zones and it is along these that geothermal prospecting seems to be most successful. In this model, temperature gradients in the upland areas are depressed downward by descending cold surface water and they may be relatively elevated in zones of convective upward circulation along major fault zones bordering or within the lowlands.

Although the major fault zones, compared to the abundant secondary faults, are difficult to locate in the Cleveland area, it is probable that the existing thermal features are fault-controlled. It is believed that, initially at least, prospecting should be concentrated along faults bordering or within the lowland blocks rather than in the upland recharge areas.

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Nine temperature gradient hole locations were proposed by Supron and Sunedco to assist in evaluating relatively large contiguous lease blocks held by these two companies (plates 3 and 4). Comments on the surface and probable subsurface conditions at these sites are included in Appendix A. Five additional sites (10 through 14) were selected on the basis of the data reviewed for this report. These sites were chosen to sample specific geological trends. The lease ownership at these locations was unknown at the time and they may not be available for drilling. A description of these sites is

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ILLUSTRATIONS

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Plate

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CONCLUSIONS

1. The concept of a Basin and Range type geothermal system appears to apply to the Cleveland-Maple Grove area, with deep circulation along faults as the source of heat.

2. Within the proposed model, there are several conditions peculiar to the locality.

   a. The thermal occurrence appears to be located at the intersection of two major fault trends, but cannot be related to a specific structure from the available data.

   b. The faults in the vicinity of the hot springs are relatively minor structures, although they may be extensions, or splayed ends of the major range-front fault zones.

3. The surface spring manifestations at Cleveland, McGregor Ranch and the mound in Mound Valley are relatively old, though deposited in the present drainage system in post-Bonneville time. The large amount of tufa deposited and the abandoned orifii in some areas suggest that the system may have choked itself off at shallow depths. A more extensive system could be present at depth.

4. Holes 1, 2 and 6 of the proposed temperature gradient sites are close to hot springs or to possible faults in the general hot spring areas which may be conduits for thermal fluid movement. Holes 3, 4, 5, 7, 8, 9 lack any obvious association with known thermal anomalies or faults. Conclusions relative to drilling conditions at the individual sites are included in Appendix A.

5. The probable areal extent of the thermal anomaly, based on distribution of thermal springs, water sampling, and travertine deposits, covers a narrow band less than 3.5 miles long and up to 1 mile in width.

6. The geochemical analysis indicates a minimum reservoir base temperature of 85°C to 100°C. These temperatures are 40° to 50°C lower than those predicted for the Preston area.

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RECOMMENDATIONS

1. Temperature gradient holes 1, 2, and 6 should be drilled first. These are the holes most likely to provide useful information.

2. Gradient holes 10 through 14, described in this report, should be reviewed in terms of the lease position in those areas. If the areas are favorable in terms of leaseholds, these holes should be drilled in preference to upland sites.

3. Holes 3 through 5 and 7 through 9 may have severe drilling problems and/or topographic effects on gradients. Of these 6 holes, numbers 4, 5, and 9 should have a higher priority for completion than 3, 7, and 8.

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INTRODUCTION

Scope of Work

The purpose of this project is to evaluate the geologic setting and the chemical character of thermal waters in the vicinity of Cleveland and Maple Grove Hot Springs. Specific goals are to determine the location and character of the structures controlling the geothermal system, to obtain additional geochemical data concerning the minimum reservoir temperatures in the system, and to evaluate temperature gradient hole sites for further exploration of the area.

The project area covers about six townships located in Mound Valley and the adjacent lower slopes of the Portneuf and Bear River Ranges, Caribou and Franklin Counties, southeastern Idaho (figure 1). The area is included in the Treasureton, Oneida Narrows Reservoir, Thatcher and Thatcher Hill 1:24,000 scale U.S. Geological Survey topographic quadrangles and by the Preston 1:250,000 scale A.M.S. sheet.

Access to the area is by means of State Highways 34 and 36 and by several improved and unimproved farm roads. The closest population center providing lodging and support services is Preston, Idaho, about 25 miles south of the center of the study area.

Method of Study

A literature search was first accomplished to obtain existing published and unpublished data for the area. The principal sources of information are included in the reference list. The area was found to be covered by relatively detailed unpublished mapping by Bright (1960) and Oriel and Platt (1968). A limited amount of geologic field work and review of aerial photographs was carried out to verify these maps and to assist in the effort to evaluate the surface and subsurface conditions at proposed temperature gradient hole sites.

Concurrently, sampling of waters from 16 thermal and non-thermal springs and wells was conducted to provide additional geochemical data for assessing the minimum reservoir temperature and areal extent of the prospect area. No systematic inventory of water wells has been made either in the field or from the Idaho Department of Water Resources files. However, due to the abundance of surface water in the area, it does not appear that a significant number of wells exist.

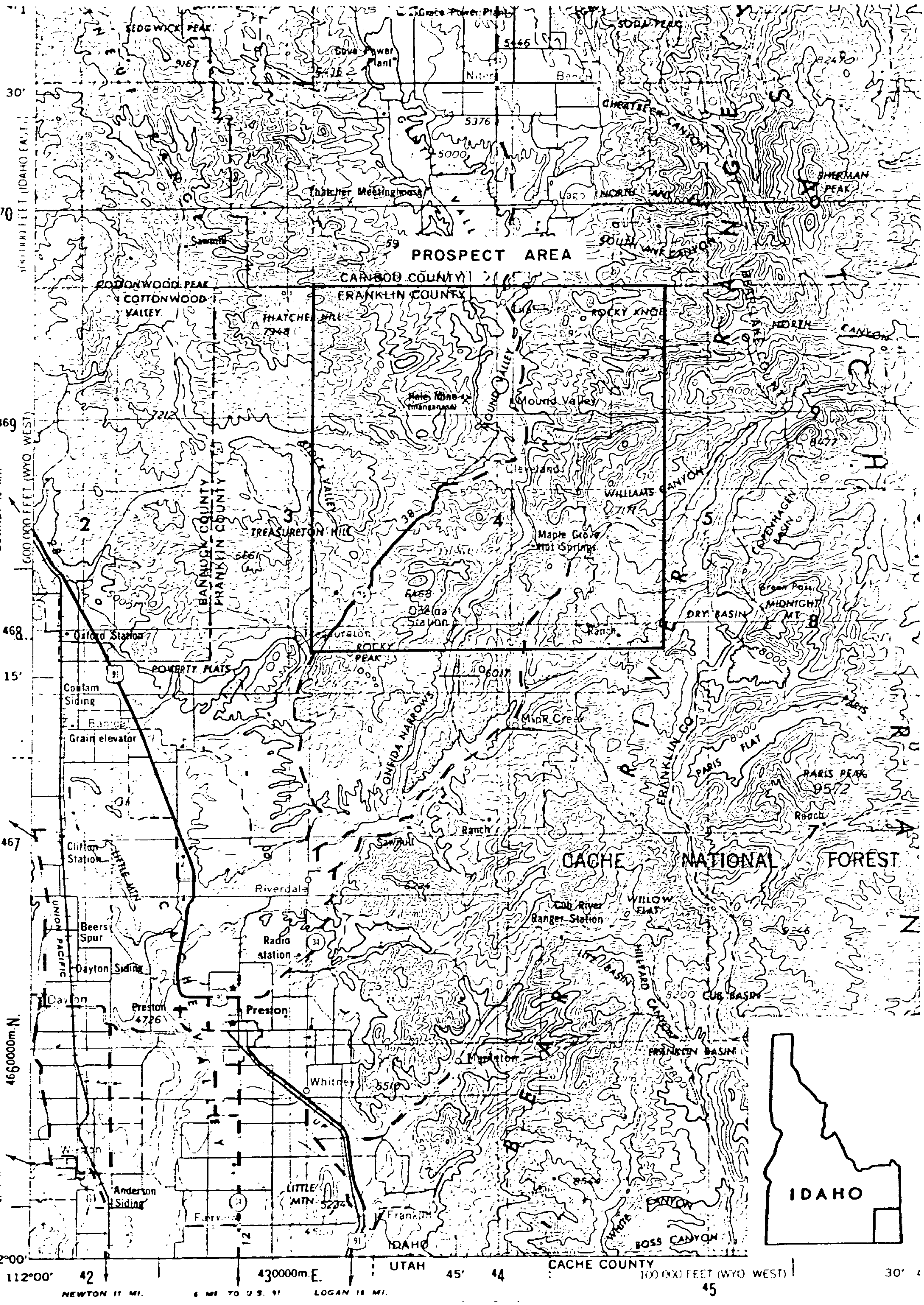

FIGURE 1. Location Map of Cleveland-Maple Grove Prospect, Idaho.
1:250,000

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GEOLOGY

Geologic Setting

The prospect area is located at the eastern edge of the Late Precambrian to Early Mesozoic Cordilleran geosyncline, adjacent to the Wyoming-Utah foreland. The oldest rocks in the geosyncline are amphibolite, schist, gneiss and granite. These are underlain by 15,000 to 25,000 feet of Proterozoic metasedimentary and minor metavolcanic rocks of greenschist metamorphic grade. The Late Precambrian rocks are apparently absent from the foreland area, indicating that the distinction between the shelf and the geosyncline was already established before the beginning of Cambrian deposition.

From Early Cambrian through Triassic time the eastern part of the geosyncline received several tens of thousands of feet of sediments, compared to about 6,000 feet of time-equivalent rocks on the Wyoming shelf. The geosynclinal section consists of thick basal Cambrian quartzites, overlain by Middle Cambrian through Mississippian age marine carbonate rocks with very subordinate amounts of sandstone and shale. In Pennsylvanian through Early Triassic time, carbonate rocks, though abundant, are exceeded by sandstones and shales. Geosynclinal sedimentation came to an end with the deposition of non-marine sandstones and shales in Late Triassic-Early Jurassic time. The recognizable tectonic activity during this long period consisted of episodic regional upwarping and downwarping defining the basins of deposition.

By Middle Jurassic time, much of the old geosyncline was being uplifted and the axes of deposition had begun a progressive shift to the east, across the hinge-line onto the former shelf. This shift culminated during Cretaceous time, in the folding of the Paleozoic-Early Mesozoic geosynclinal rocks and the development of major overthrust zones in which the geosynclinal rocks were displaced to the east, over the shelf margin. The project area is located on the western side, and in the hanging wall of the Bannock thrust, one of the major thrust faults of the region.

During early Cenozoic time the area was apparently undergoing erosion, but by Late Miocene or Early Pliocene time, large lacustrine basins had developed, probably coincident with the onset of Basin and Range faulting. Thick fluvial and lacustrine deposits occur over large areas in these basins. Increasing intensity of normal faulting in Late Pliocene and Pleistocenc time gave rise to

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

the present arrangement of horst block ranges and graben valleys in the region. Locally thick sections of fluvial and lacustrine sediments were deposited in these intermontane basins during Quaternary time. Igneous activity during the Cenozoic Era was intense to the north of the project area and in many other parts of the province, but appears to be absent here.

This setting is similar to that of geothermal occurrences in many other areas of the Basin and Range Province. However, the tectonic history here is complicated by Laramide thrusting that is not present in some areas, while the Cenozoic volcanic phase is lacking. The same models of geothermal systems currently employed elsewhere in the region are believed to be appropriate to the study area.

Stratigraphy

The stratigraphic section consists of Holocene alluvium and colluvium, Pleistocene lake beds and old slope deposits, Late Tertiary lacustrine and fluvial sediments, Ordovician quartzite and carbonate rocks, and Cambrian limestone, dolomite, shale and quartzite. Fairly detailed descriptions of these units in the Cleveland area have been made (Bright, 1960). The columnar section included by Bright (1960) has been reproduced here (Plate 1). These data should be useful in evaluating stratigraphic information from planned temperature gradient holes to be drilled in the area.

Two aspects of the stratigraphy are of particular importance to the temperature gradient hole project. One concerns the reservoir character of the rocks while the other relates to the drilling difficulty which might be encountered.

The reservoir character is poorly-known, as there has been very little exploration for deep groundwater in the area. Quaternary gravels are porous and water-bearing. Rocks in the Tertiary Salt Lake Group are fine-grained, poorly sorted and tuffaceous. Their porosity potential appears to be generally poor. The Paleozoic rocks appear to be recrystallized or well-cemented and to lack interstitial porosity. Secondary fracture porosity may be present in both carbonate rocks and quartzites. In the carbonate rocks, particularly the Nounan Formation, solution cavities are frequently well-developed in outcrop areas and may indicate secondary porosity potential.

The nature of the stratigraphic section indicates that various drilling problems may occur. For one, Quaternary sediments contain non-lithified rocks and gravels and bouldery colluvium. They may cause caving problems and lost circulation. For another, the Paleozoic section, particularly the Brigham Quartzite, is very hard. Penetration rates will be low. Circulation may be lost in fractures or solution cavities. A description of the stratigraphy at specific temperature gradient hole sites is provided in Appendix A.

Structure

Two groups of structures in the area result from two major periods of deformation. The earlier group belongs to the Cretaceous Laramide episode and the later to the Cenozoic Basin and Range episode.

Laramide deformation is characterized by compressional folding and especially by the development of major low angle thrust faults. However, numerous westerly-trending tear faults and a mosaic of tensional faults from this period are observed, particularly in the upper plates of the thrusts. The Bear River Range to the east of the prospect area is a large faulted syncline in the hanging wall of the Paris segment of the Bannock Thrust zone (plate 2). The lip of the thrust itself is seen along the east side of the range. This major low-angle thrust dips to the west, but the location of the root zone is unknown. Thus, it is uncertain if it passes beneath the project area at great depth. No thrust faults have been mapped in the surface of the project area. Some of the long, west-northwest, west and west-southwest trending faults within the Bear River Range are probably tear faults of Laramide age but the criteria for distinguishing them from younger faults are not evident.

Numerous tensional faults of the Late Cenozoic Basin and Range deformational episode have been superimposed on the Laramide structures. The larger faults of this system define the present horst block ranges and graben valleys. The Portneuf Range bordering the project area on the west and south is a fault block tilted toward the northeast. Boundary faults believed to flank the range on both sides are masked by Quaternary sediments and precise locations for the faults are uncertain. The displacement along the west side of the range is believed to be greater than that along the east side. The strike of the boundary faults and of many of the longitudinal faults within the range is about N 30° W. This trend is discordant to that of the Bear River Range to the east and the two uplifts intersect in the project area. Interval faulting within the Portneuf Range is very complex with common fault strikes of N 30° E to nearly E-W.

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

The Bear River Range, to the east of the prospect area, trends north to north-northwest, which is more characteristic of the ranges of the region. This block is divided into two main segments at its intersection with the Portneuf trend. Boundary faulting along the west side of the range, adjacent to Cache Valley on the south and Gem Valley on the north, becomes indistinct in the project area.

Faulting within the Bear River Range uplift has a predominantly north-northwest strike, with subordinate north-northeast to east strikes. The pattern is especially complex where the trends intersect.

Within the immediate project area, the faults shown on Plate 3 are derived principally from mapping by Oriel and Platt (1968). These structures are based almost entirely on stratigraphic discontinuities and anomalous attitudes. Actual fault planes are almost never visible due to the extensive cover of Quaternary deposits. Most of the faults have displacements of a few hundreds of feet. Many smaller faults exist but were not mapped. In this complex structural setting the following faults appear to be particularly important due to their large stratigraphic offset or to their association with important regional faults seen on plates 2 and 3.

1. Bear River Range Boundary Fault Zone: This is a North-northeast-trending segment of the range front fault zone inferred to extend beneath the Quaternary cover along the east side of Mound Valley. It may project toward the Treasureton lineament or splay out into several faults in the subsurface. The precise location of the zone is not known.

2. Portneuf Range Boundary Fault Zone: It is likely that the boundary fault along the northeast side of the Portneuf Range projects beneath the Quaternary sediments along the southwest side of Mound Valley, but the location of the feature is uncertain. It is likely to diminish in displacement and to change strike from southeasterly to easterly, and merge with faults in the McGregor Ranch area.

3. Rocky Peak-Oneida Power Plant Fault and Graben Complex: Two faults and an intervening graben filled with Tertiary Salt Lake Group sedimentary rocks make up this structural zone. The displacements along these faults amount to several thousand feet. The variations

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MURRAY C. GARDNER

in fault strikes from about N 30° W to east-west and again to N 30° W in the Bear River Range are typical of the structural changes that take place at the Portneuf-Bear River intersection.

4. Treasureton Lineament: This possible structure was identified as a major fault of probable Laramide age (Bright, 1960). It has been ignored on subsequent maps (Oriel and Platt, 1968; Mitchell and Bennett, 1979). The northeast trends of aligned drainages in this area suggest that such a structure may exist. Its relationship to the Bear River fault is uncertain due to their possibly different ages and origins.

In general, it appears that the high density of faulting in the Cleveland-Maple Grove area has favored development of deep circulation of groundwater and occurrence of thermal springs. However, the relationship of individual faults to active and fossil thermal springs in the prospect area cannot be determined with certainty. The large tufa mound in Mound Valley, Cleveland Hot Springs and the extensive tufa terrace in the McGregor Ranch area, all could result from the intersection of the Bear River Range and Portneuf Range frontal fault systems in this immediate area. The location of Maple Grove Hot Springs is more remote from this intersection. Only an intra-range fault of relatively small displacement is associated with the Maple Grove Hot Springs area. The structural setting is not distinguished from others in the area.

At the other major structures mentioned above, neither the Rocky Peak-Oneida Power Plant graben and associated faults nor the Treasureton lineament have thermal spring anomalies associated with them.

The age of the most recent movement of Basin and Range faults in the project area is uncertain. There is no surface evidence of offset in Quaternary lake beds in Mound Valley. Manganese mining operations in Quaternary sediments beneath the McGregor Ranch tufa terrace have uncovered stratigraphic offsets of as much as 20 feet (Bright, 1960). These may be due to penecontemporaneous slumping rather than to faulting.

Hydrothermal Mineral Deposits

There are several types of mineral deposits in the project area which are associated with fossil and recent hydrothermal

JAMES B. KOENIG (415) 527-9876
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activity. Traces of copper, lead and zinc mineralization occur in Cambrian rocks, but these are believed to be Tertiary age or older. Thick calcite veins in Cambrian limestone, located in the northeast quarter of Section 33, T. 13 S., R. 40 E., are also considered to be older than Quaternary.

Tufa deposits of impressive volume occur around active and fossil thermal mineral spring sites at Maple Grove, Cleveland, McGregor Ranch (from the center of the south half of Section 30 to the south line of Section 31, T. 12 S., R. 41 E.) and at the large mound centered in the southeast quarter of Section 13, T. 12 S., R. 40 E. Additional small deposits have been reported at unspecified localities on Williams Creek and along the west side of the valley in the vicinity of the so-called Hale Mine (northeast quarter of Section 23, T. 12 S., R. 40 E.) (Bright, 1960). These deposits are an indication of the potential extent of the deep thermal mineral water system which may exist in the area.

Manganese oxide deposits occur at the Hale Mine and under the large tufa terrace at McGregor Ranch (northeast quarter of the northwest quarter of Section 31, T. 12 S., R. 41 E.). These occurrences consist of thin earthy manganese oxide lenses in sand, clay and marl of Quaternary lacustrine origin (Hewett, 1928). The largest deposit, at McGregor Ranch, was mined intermittently from 1826 to 1942. The greatest production was about 1,200 tons of ore averaging 45% MnO_2, obtained in 1926 and 1927. This deposit appeared to be centered in and around a central chimney, possibly an old spring orifice. Bright (1960) concluded that all of the manganese occurrences represent deposition from former hot springs along the shore of Pleistocene lakes, either directly in the tufas or in adjacent lake sediments.

Manganese-depositing hot springs are known in several other parts of the region, among them Lava Hot Springs, Idaho, and Abraham Hot Springs, in Utah. In discussing deposits of this type, Hewett and Fleisher (1960) conclude that the waters originate at great depth but they do not specifically propose an igneous origin for any of the components.

Hydrology

The main topographic elements in the hydrologic framework of the study area are the Gentile Valley-Mound Valley depression, flanked on the west and south by the Portneuf Range and on the east by the Bear River Range. The area also includes the northern end of Cache Valley, south of the Treasureton Pass segment of the Portneuf

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

Range. All of this area is drained by the Bear River and its tributaries.

Precipitation varies widely in this area, depending on elevation. About 15 inches of moisture falls annually in the valley, compared with 25 to 40 inches in the high mountains. Surface water supplies most of the irrigation needs of the valley agricultural areas and very few wells have been drilled for other than domestic use. Low consumption of ground water in relation to the probable water in storage in Quaternary sediments suggests no conflict between present uses and potential geothermal development.

The hydrologic character of the major geologic units in the area is shown in table 1. The most important aquifers are in the alluvium and Pleistocene sedimentary deposits of the valleys. These aquifers are generally under weak artesian pressure in the central parts of valleys, and some wells flow at the land surface. Except in the central part of Gentile Valley where the water level is within about 5 feet of the land surface, the depth to water averages 20 to 30 feet below the surface (Dion, 1969). There are practically no water well data published pertinent to the part of the valley in the prospect area. The surrounding uplands are ground water recharge areas from which precipitation seeps downward and valleyward through joints and faults.

The paths taken by ground water may be complex. A model for circulation in the Basin and Range setting has been proposed by Illian (1970). Three ground water systems have been described in this setting, based on flow distance, depth of circulation, and to some degree on the types of geologic materials through which the ground water moves. These, in turn, effect the chemical character and the temperatures found in each system. The three systems are designated as local, intermediate and regional in figure 2.

In the local ground water system, the recharge and discharge points are close together. The water may circulate only a short distance below the water table or may be part of a perched system. Low temperatures and low salinities are characteristic of this system. The water is typically of bicarbonate type. The upland springs in the project area appear to belong to this flow pattern.

Intermediate flow systems represent moderate flow distances and depths. Temperature and water compositions vary widely. Some

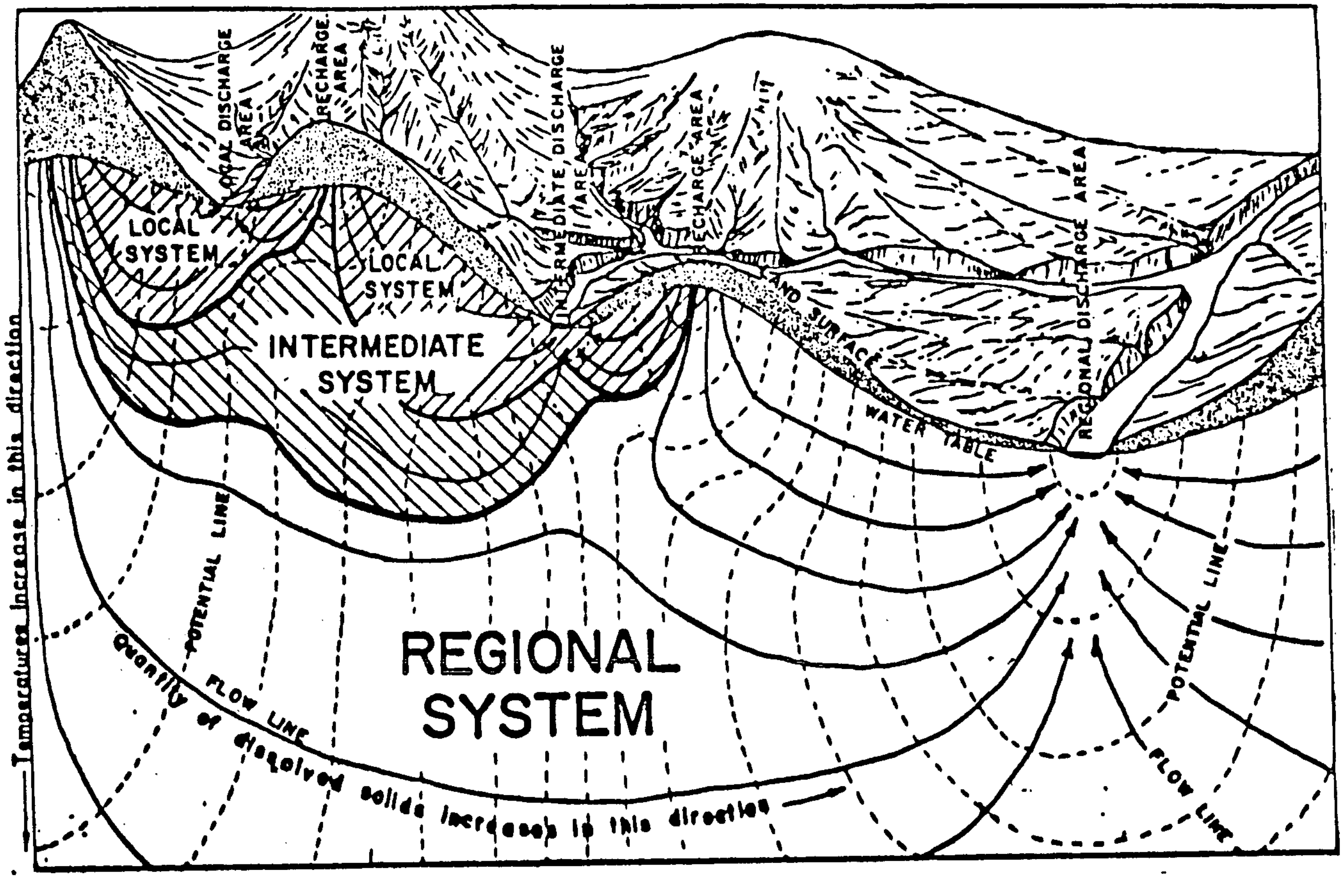

FIGURE 2. Salient features of local, intermediate, and regional ground-water flow systems (from Illian, 1970).

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MURRAY C. GARDNER

Table 1 Summary of geologic units and their hydrologic characteristics (from Dion, 1969).

System	Series	Geologic unit	Availability of water		Adequacy as source of water supply		
			Yield (gpm)	Specific capacity (gpm/ft of drawdown)	Domestic and stock	Irri- gation	Industrial and municipal
Quaternary	Holocene	Alluvium	500-1,500	As much as 150	Good	Good	Good
Quaternary	Pleistocene	Sediments	500-1,500?	As much as 150?	Good	Poor to Good	Poor to Good
Tertiary	Pliocene(?)	Salt Lake Formation	Erratic 0-1,800	Erratic 0-75	Fair	Poor	Poor
Pre-Tertiary		Undiffer- entiated bedrock	-	-	Fair	Poor	Poor

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MURRAY C. GARDNER

occurrences of intermediate aspect may result from mingling of water from local and regional systems.

The regional flow system receives recharge from the highest water table elevations and discharges in the lowest part of the ground water basin. The flow paths are long and circulation takes place to great depths. In this system water may move laterally along major fault zones, where permeable, from one structural basin to another. Water in the regional flow system characteristically has the highest temperatures and salinities, with relatively high concentrations of chloride and sulfate relative to bicarbonate. The principle hot springs in the Cleveland and Maple Grove groups appear to belong to the regional flow system. Slightly mineralized and warm waters in the McGregor Ranch tufa terrace and in the large tufa mound in Mound Valley probably reflect mixing of regional with intermediate system waters.

The deep-circulating part of this system is that which is of significance to geothermal occurrences. Most of the known geothermal systems in the Basin and Range province are related to the major deepseated fault zones and it is along these that geothermal prospecting seems to be most successful. In this model, temperature gradients in the upland areas are depressed downward by descending cold surface water and they may be relatively elevated in zones of convective upland circulation along major fault zones bordering or within the lowlands.

Although the major fault zones, compared to the abundant secondary faults, are difficult to locate in the Cleveland area, it is probable that the existing thermal features are fault-controlled. It is believed that, initially at least, prospecting should be concentrated along faults bordering or within the lowland blocks rather than in the upland recharge areas.

Temperature Gradient Hole Evaluation

Nine temperature gradient hole locations were proposed by Supron and Sunedco to assist in evaluating relatively large contiguous lease blocks held by these two companies (plates 3 and 4). Comments on the surface and probable subsurface conditions at these sites are included in Appendix A. Five additional sites (10 through 14) were selected on the basis of the data reviewed for this report. These sites were chosen to sample specific geological trends. The lease ownership at these locations was unknown at the time and they may not be available for drilling. A description of these sites is

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JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

also included in Appendix A, in case any are added to the original program as supplementary or alternative locations.

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JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

GEOCHEMISTRY

Sampling Program

For geochemical evaluation of the Maple Grove prospect 16 water samples were collected for chemical analysis during April 28 to May 5, 1980. Three samples were from orifii at or near Maple Grove Hot Spring, of which one was a duplicate collected to monitor laboratory performance. Four samples were from hot springs near Cleveland, here termed Cleveland Hot Spring, Bear River Springs and Cow Hot Spring. One sample was from a mildly thermal spring termed The Mound on a travertine mound about 2.5 miles north of the springs near Cleveland. The remaining samples were from cold springs, wells and a creek adjacent to the hot springs and in the general area. All sample localities are shown on plate 4.

Portions of each sample were treated with acid at the time of collection, to prevent precipitation of calcium carbonate during storage prior to analysis.* Samples for laboratory determination of pH and HCO_3 were stored in glass bottles to prevent evolution of CO_2. Samples for other anions and for cations were also filtered through a 0.45 μ membrane in the field. pH was measured nightly at the field base using a meter, on samples sealed in completely filled glass bottles and collected whenever possible by immersion directly in the spring. Samples for silica were diluted in the field 1:10 with de-ionized water but when low silica levels were encountered, measurements proceeded in the filtered, untreated samples, using atomic absorbtion. Analyses were by AMTECH Labs, San Diego, California.

Results

A field data record for each sample is reproduced in Appendix B. Particularly notable field characteristics of all the hot springs are the presence of travertine, common gas emissions and high flow rates. Mitchell (1976) reported that near Cleveland old travertine is present, but no fresh deposits are forming. During sampling for this report travertine was observed at Cleveland area sample sites 6, 7 and 10, and current deposition of travertine appeared doubtful. Travertine is abundant at Maple Grove Hot Springs, and appears to be currently forming. Gas emissions at all the springs are probably dominated by CO_2.

Results of analyses are presented below as tables 2 to 4.

*Non-acidied for portions stored more than one month did not form visible precipitates.

TABLE ..2....

CHEMICAL ANALYSES IN MG/L.

Thermal and non-thermal groundwaters, Maple Grove prospect

TABLE HEADINGS:
N=SAMPLE NUMBER. DATE=SAMPLE COLLECTION DATE, YR-MO-DAY.
TC=TEMPERATURE IN DEGREES CENTIGRADE. PHF=FIELD PH. PHL=
LAB PH. CA---CL=IONIC SPECIES, CONCENTRATIONS IN MG/L.
SIO2=SILICA IN MG/L. TDSS=CALCULATED TDS.
EC=CONDUCTIVITY AT 25 DEGREES, MICROMHOS/L. B=ATOMIC BORON IN
MG/L. F--- Br =IONIC SPECIES, MG/L. S=SULFIDE MG/L, LAB.*
H2SF=H2S MG/L, FIELD.* CO2F=FIELD MEASUREMENT OF CO2, MG/L.*
COM=LINE NUMBER OF COMMENTARY TO THE ANALYSIS (IN
SEPARATE TABLE).

NOTE: ALL 9'S MEANS NO DATA AVAILABLE. 0.0 MEANS BELOW
DETECTION LIMIT OF ANALYSIS.

*not included

N	NAME	DATE	TC	PHF	PHL	CA	MG	NA	K
1.0	MAPLE GR.	800428	81	6.55	6.50	92.9	22.8	480.0	82.5
1.1	MAPLE GR.	800428	81	6.55	6.51	90.6	21.4	474.0	82.9
2.0	MAPLE GR.	800429	16	7.20	7.51	36.7	11.8	7.9	1.4
3.0	MAPLE GR.	800429	67	6.60	6.43	91.5	23.0	487.0	84.7
4.0	COLD SP.	800429	13	7.21	7.28	86.8	13.6	12.7	2.1
5.0	CLEV.C.SP	800501	13	7.00	7.30	70.0	14.1	40.5	8.7
5.1	CLEV.WELL	800501	13	6.90	7.02	59.7	11.9	13.0	2.6
6.0	CLEV.HOTS	800501	41	6.61	6.69	246.0	67.2	456.0	111.0
7.0	BEAR R.SP	800501	60	6.20	6.73	200.0	57.3	412.0	96.1
8.0	BEAR R.SP	800502	54	6.37	6.43	212.0	54.4	417.0	102.0
9.0	THE MOUND	800502	36	6.28	6.23	294.0	78.5	242.0	52.8
10.0	COW H.SP.	800502	76	6.40	6.50	184.0	47.8	416.0	100.0
11.0	MC GREGOR	800503	20	7.01	7.02	78.0	27.0	30.0	6.0
12.0	MC GREGOR	800503	13	7.10	7.20	79.3	29.0	30.5	6.8
13.0	BURTON WE	800504	14	7.30	6.98	122.0	20.3	33.4	11.6
14.0	BURTON SP	800505	11	7.52	7.20	18.7	4.5	5.1	0.7
15.0	COTTONW.C	800505	7	7.95	8.01	31.8	5.4	1.7	0.9

N	LI	HCO3	SO4	CL	B	F	NH3	SIO2	TDSS	Flow (lpm)
1.0	1.12	484.0	232.0	622.0	1.84	1.20	1.640	62	1772	900
1.1	1.11	481.0	245.0	625.0	2.53	1.48	2.030	60	1777	900
2.0	0.03	157.0	14.4	10.5	0.14	0.48	0.000	13	161	9
3.0	1.11	492.0	235.0	633.0	1.91	1.15	1.640	65	1798	9
4.0	0.02	330.0	10.5	18.1	0.44	0.27	0.000	14	307	21
5.0	0.07	220.0	50.5	62.5	0.50	0.44	0.000	12	355	low
5.1	0.02	206.0	21.8	25.9	0.41	0.29	0.000	11	237	well
6.0	1.19	799.0	655.0	588.0	2.64	1.61	2.100	37	2519	50
7.0	1.03	633.0	522.0	519.0	2.13	1.54	2.200	46	2120	>200
8.0	1.11	603.0	573.0	536.0	2.21	1.75	1.930	47	2193	~130
9.0	0.55	1180.0	307.0	329.0	2.02	1.15	0.499	29	1888	3-5
10.0	1.09	593.0	494.0	547.0	2.01	1.68	2.060	54	2083	>200
11.0	0.06	420.0	32.7	27.8	0.51	0.48	0.000	13	410	180-240
12.0	0.07	426.0	35.1	30.1	0.27	0.44	0.000	12	422	low
13.0	0.12	289.0	145.0	56.3	0.27	0.76	0.000	41	532	well
14.0	0.01	78.9	7.4	9.3	0.12	0.27	0.011	14	85	~900
15.0	0.00	121.0	5.3	4.7	0.33	0.30	0.000	10	110	creek

TABLE ..3...

Thermal and non-thermal groundwaters, Maple Grove prospect

ANALYSIS IN MILLIEQUIVALENTS;
CALCULATED CONDUCTIVITY;
IONIC BALANCE;
IONIC RATIOS

TABLE HEADINGS:
N=SAMPLE NUMBER. CA THROUGH CL, F AND NH3=CONCENTRATION IN
MILLIEQUIVALENTS/L. B=CONCENTRATION IN MMOLES/L. ECOBS=
MEASURED CONDUCTIVITY(LAB). ECCAL=CALCULATED CONDUCTIVITY.
OBCA=ECOBS/ECCAL. SCAT=SUM OF CATIONS(MEQ/L). SAN=SUM OF ANIONS
(MEQ/L). DIF=((SCAT-SAN)/(SCAT+SAN))*100. CAF=CA/SCAT. MGF=
MG/SCAT. NKF=(NA+K)/SCAT. HCF=(HCO3+CO3)/(HCO3+CO3+SO4+CL).
SOF=SO4/(HCO3+CO3+SO4+CL). CLF=CL/(HCO3+CO3+SO4+CL). CLF=CL/
(HCO3+CO3+SO4+CL). BCL=(B/CL)*100. FCL=(F/CL)*100. NHCL=
(NH3/CL)*100. I=IONIC STRENGTH (CALC. WITH MOLAR CONCENTRA
TIONS).

ALL 9'S MEANS NO DATA OR INSUFFICIENT DATA TO PERMIT
CALCULATION

N	CA	MG	NA	K	HCO3	SO4	CL	B	F	NH 3
1.0	4.64	1.87	20.87	2.11	7.93	4.83	17.54	0.170	0.063	0.0963
1.1	4.52	1.76	20.61	2.12	7.88	5.10	17.63	0.234	0.078	0.1191
2.0	1.83	0.97	0.35	0.04	2.57	0.30	0.30	0.013	0.025	0.0000
3.0	4.57	1.89	21.18	2.17	8.06	4.89	17.85	0.177	0.061	0.0963
4.0	4.33	1.12	0.55	0.05	5.41	0.22	0.51	0.040	0.014	0.0000
5.0	3.49	1.16	1.76	0.22	3.61	1.05	1.76	0.047	0.023	0.0000
5.1	2.98	0.98	0.57	0.07	3.38	0.45	0.73	0.038	0.015	0.0000
6.0	12.28	5.53	19.83	2.84	13.09	13.64	16.58	0.244	0.085	0.1233
7.0	9.98	4.71	17.92	2.46	10.37	10.87	14.64	0.197	0.081	0.1291
8.0	10.58	4.47	18.13	2.61	9.88	11.93	15.12	0.204	0.092	0.1133
9.0	14.67	6.46	10.52	1.35	19.34	6.39	9.28	0.187	0.061	0.0293
10.0	9.18	3.93	18.09	2.56	9.72	10.28	15.43	0.186	0.088	0.1209
11.0	3.89	2.22	1.30	0.15	6.88	0.68	0.78	0.048	0.025	0.0000
12.0	3.96	2.38	1.33	0.17	6.98	0.73	0.85	0.025	0.023	0.0000
13.0	6.09	1.67	1.45	0.30	4.74	3.02	1.59	0.025	0.040	0.0000
14.0	0.93	0.37	0.22	0.02	1.29	0.15	0.26	0.011	0.014	0.0006
15.0	1.59	0.45	0.08	0.02	1.98	0.11	0.13	0.030	0.016	0.0000

N	ECOBS	ECCAL	OBCA	SCAT	SAN	SUM	DIF	I
1.0	3463	3535	0.980	29.493	30.304	59.80	-1.36	0.036
1.1	3497	3536	0.989	29.013	30.610	59.62	-2.68	0.036
2.0	311	317	0.982	3.183	3.169	6.35	0.22	0.005
3.0	3488	3585	0.973	29.800	30.808	60.61	-1.66	0.036
4.0	623	599	1.040	6.054	6.137	12.19	-0.68	0.009
5.0	710	707	1.005	6.637	6.419	13.06	1.67	0.009
5.1	470	469	1.002	4.590	4.560	9.15	0.33	0.007
6.0	4740	4907	0.966	40.470	43.314	83.78	-3.39	0.058
7.0	4165	4158	1.002	35.066	35.879	70.94	-1.15	0.048
8.0	4221	4293	0.983	35.794	36.928	72.72	-1.56	0.050
9.0	3549	3695	0.960	33.000	35.008	68.01	-2.95	0.048
10.0	4011	4084	0.982	33.760	35.430	69.19	-2.41	0.046
11.0	714	791	0.903	7.571	8.348	15.92	-4.88	0.011
12.0	868	817	1.062	7.842	8.561	16.40	-4.38	0.012
13.0	1005	1037	0.969	9.506	9.343	18.85	0.87	0.015
14.0	149	166	0.900	1.544	1.710	3.25	-5.08	0.002
15.0	193	213	0.905	2.133	2.225	4.36	-2.12	0.003

N	CAF	MGF	NKF	HCF	SOF	CLF	BCL	FCL	FSAN	NHCL
1.0	0.157	0.064	0.779	0.262	0.159	0.579	0.97	0.36	0.21	0.55
1.1	0.156	0.061	0.784	0.258	0.167	0.576	1.33	0.44	0.25	0.68
2.0	0.575	0.305	0.120	0.812	0.095	0.093	4.40	8.53	0.80	0.00
3.0	0.153	0.063	0.783	0.262	0.159	0.579	0.99	0.34	0.20	0.54
4.0	0.715	0.185	0.100	0.881	0.036	0.083	7.88	2.76	0.23	0.00
5.0	0.526	0.175	0.299	0.562	0.164	0.275	2.65	1.33	0.36	0.00
5.1	0.649	0.213	0.138	0.740	0.100	0.160	5.26	2.09	0.33	0.00
6.0	0.303	0.137	0.560	0.302	0.315	0.383	1.47	0.51	0.20	0.74
7.0	0.285	0.134	0.581	0.289	0.303	0.408	1.35	0.55	0.23	0.88
8.0	0.296	0.125	0.579	0.268	0.323	0.409	1.35	0.61	0.25	0.75
9.0	0.445	0.196	0.360	0.552	0.183	0.265	2.01	0.65	0.17	0.32
10.0	0.272	0.116	0.612	0.274	0.290	0.435	1.21	0.57	0.25	0.78
11.0	0.514	0.293	0.193	0.825	0.082	0.094	6.06	3.22	0.30	0.00
12.0	0.505	0.304	0.191	0.815	0.085	0.099	2.90	2.75	0.27	0.00
13.0	0.640	0.176	0.184	0.507	0.323	0.170	1.59	2.53	0.43	0.00
14.0	0.604	0.242	0.154	0.756	0.090	0.154	4.11	5.36	0.83	0.25
15.0	0.744	0.210	0.046	0.891	0.049	0.060	22.77	11.93	0.71	0.00

TABLE ..4...

Thermal and non-thermal groundwaters, Maple Grove prospect

CHEMICAL GEOTHERMOMETERS

.TABLE HEADINGS:

N=SAMPLE NUMBER. GEOTHERMOMETERS--QTZC=QUARTZ CONDUCTIVE,
QTZA=QUARTZ ADIABATIC, BCR=BETA CRISTOBALITE, CHAL=CHALCEDONY,
AMOR=AMORPHOUS SILICA, SQ=SQR(CA)/NA, B43=NA-K-CA WITH B=4/3,
B13=NA-K-CA WITH B=1/3, NKC=NA-K-CA VALUE OF CHIOCE; NAK=NA-K

CMG=MG-CORRECTED NKC, PCC=PCO2-CORRECTED NKC

R=FRACTION MG FOR CMG. DMG=MG-CORRECTION.

PH=SAMPLE PH. HCO3=MEQ/L HCO3. PCO2=PARTIAL PRESSURE OF CO2
AT SAMPLE TEMPERATURE. -LOG PCO2=PH-LOG(HCO3)-7.689-(4.22*
10↑(-3)*TC)-(3.54*10↑(-5)*TC↑2), USING CONCENTRATION HCO3
ALL TEMPERATURES IN DEGREES CENTIGRADE. ALL 9'S MEANS NO DATA
OR GEOTHERMOMETER INAPPLICABLE.
REFERENCES: FOURNIER (1976, 1978 AND 1979), PACES (1975).

C

N	TC	QTZC	QTZA	BCR	CHAL	AMOR	SQ	B43	B13	NKC	CMG	PCC	NAK
1.0	81	112	111	14	83	-5	2.31	170	218	218	90	57	218
1.1	81	111	110	13	82	-6	2.31	171	219	219	94	58	219
2.0	16	49	56	-43	16	-58	87.64	10	153	10	999	-26	221
3.0	67	114	113	16	85	-3	2.26	172	219	219	90	62	219
4.0	13	51	57	-41	18	-56	84.27	9	149	9	999	-29	213
5.0	13	46	53	-45	14	-60	23.73	58	185	58	999	6	238
5.1	13	41	49	-49	8	-64	68.27	21	163	21	999	-22	233
6.0	41	89	91	-7	58	-25	3.95	151	229	229	74	50	250
7.0	60	98	99	1	68	-17	3.94	149	226	226	71	42	246
8.0	54	99	100	2	68	-17	4.01	151	229	229	79	46	250
9.0	36	77	81	-17	46	-35	8.14	106	206	206	62	17	239
10.0	76	106	106	8	76	-11	3.75	154	229	229	80	46	249
11.0	20	49	56	-43	16	-58	33.82	43	175	43	999	-8	231
12.0	13	46	53	-45	14	-60	33.54	46	180	46	999	-5	241
13.0	14	93	95	-3	63	-21	37.99	54	203	54	999	5	287
14.0	11	51	57	-41	18	-56	97.98	1	138	1	999	-27	197
15.0	7	38	47	-51	6	-66	374.43	-7	184	-7	999	-31	339

N	R	DMG	CMG	PH	HCO3	PCO2	PCC
1.0	21.7	127	90	6.55	7.93	0.4097	57
1.1	20.9	125	94	6.55	7.88	0.4071	58
2.0	99.9	999	999	7.20	2.57	0.0095	-26
3.0	21.9	129	90	6.60	8.06	0.2736	62
4.0	99.9	999	999	7.21	5.41	0.0187	-29
5.0	99.9	999	999	7.00	3.61	0.0203	6
5.1	99.9	999	999	6.90	3.38	0.0239	-22
6.0	26.8	155	74	6.61	13.09	0.2683	50
7.0	27.5	155	71	6.20	10.37	0.7684	42
8.0	25.3	149	79	6.37	9.88	0.4415	46
9.0	28.7	144	62	6.28	19.34	0.7820	17
10.0	25.1	149	80	6.40	9.72	0.6335	46
11.0	99.9	999	999	7.01	6.88	0.0412	-8
12.0	99.9	999	999	7.10	6.98	0.0312	-5
13.0	99.9	999	999	7.30	4.74	0.0135	5
14.0	99.9	999	999	7.52	1.29	0.0021	-27
15.0	99.9	999	999	7.95	1.98	0.0012	-31

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Original analytical results from the lab were presented to three significant figures for all species determined; the computer-processed results modify this by printing a uniform number of digits to the right of the decimal point, but no loss of significant data occurs.

Table 5 presents analyses of Maple Grove Hot Springs and hot springs near Cleveland, reproduced from Mitchell (1976). Spring compositions tabulated by Mitchell (1976) and the newer ones in table 2 are virtually identical except for reported SiO_2, as shown below.

	average SiO_2 mg/1 (number of samples)		
Spring	this report	Mitchell (1976)	Difference
Cleveland H.S.	37 (1)	53 (2)	16
Bear River, Cow H.S.	49 (3)	62 (3)	13
Maple Grove H.S.	62 (3)	85 (3)	23

Most likely the reports of higher SiO_2 by Mitchell (1976) represent a systematic analytical bias in his results, ours, or both. Comparable spring temperatures, flow rates and concentrations of other elements lead to discounting a real difference such as might be due to mixing or disequilibrium under conditions of low flow rate. In either case the levels of SiO_2 reported are fairly low and use of Mitchell's (1976) results do not change our principal conclusions, below.

Two re-determinations of SiO_2 were performed by AMTECH Labs since this report was first drafted. These are 66.7 mg/l in sample 1 and 69.2 mg/l in sample 3, both from Maple Grove Hot Springs. Each re-determination is about 4.5 mg/l above the SiO_2 concentrations first reported, but represents a change of less than 10%, which is an acceptable analytical uncertainty, and not significant in interpretation of the data.

Discussion

Figure 3 is a trilinear composition diagram (Piper diagram) including all the sample analyses, plus sample temperatures and total salinity in meq/l. The cool groundwaters have low salinities and $Ca\text{-}Mg\text{-}HCO_3$ compositions. The thermal waters have moderate salinities of about 60 to 80 meq/l or 1,700 to 2,500 mg/l, and Na-mixed anion compositions, with quite notably high Ca and Mg. The thermal waters from the Cleveland area and Maple Grove cluster tightly in two separate composition fields. Although it initially appears that the Cleveland area water could be a mixture of Maple Grove type water with dilute cool recharge, the Cleveland water is actually the

FIGURE 3. Trilinear composition diagram, thermal and cool groundwaters of the Cleveland-Maple Grove prospect area.

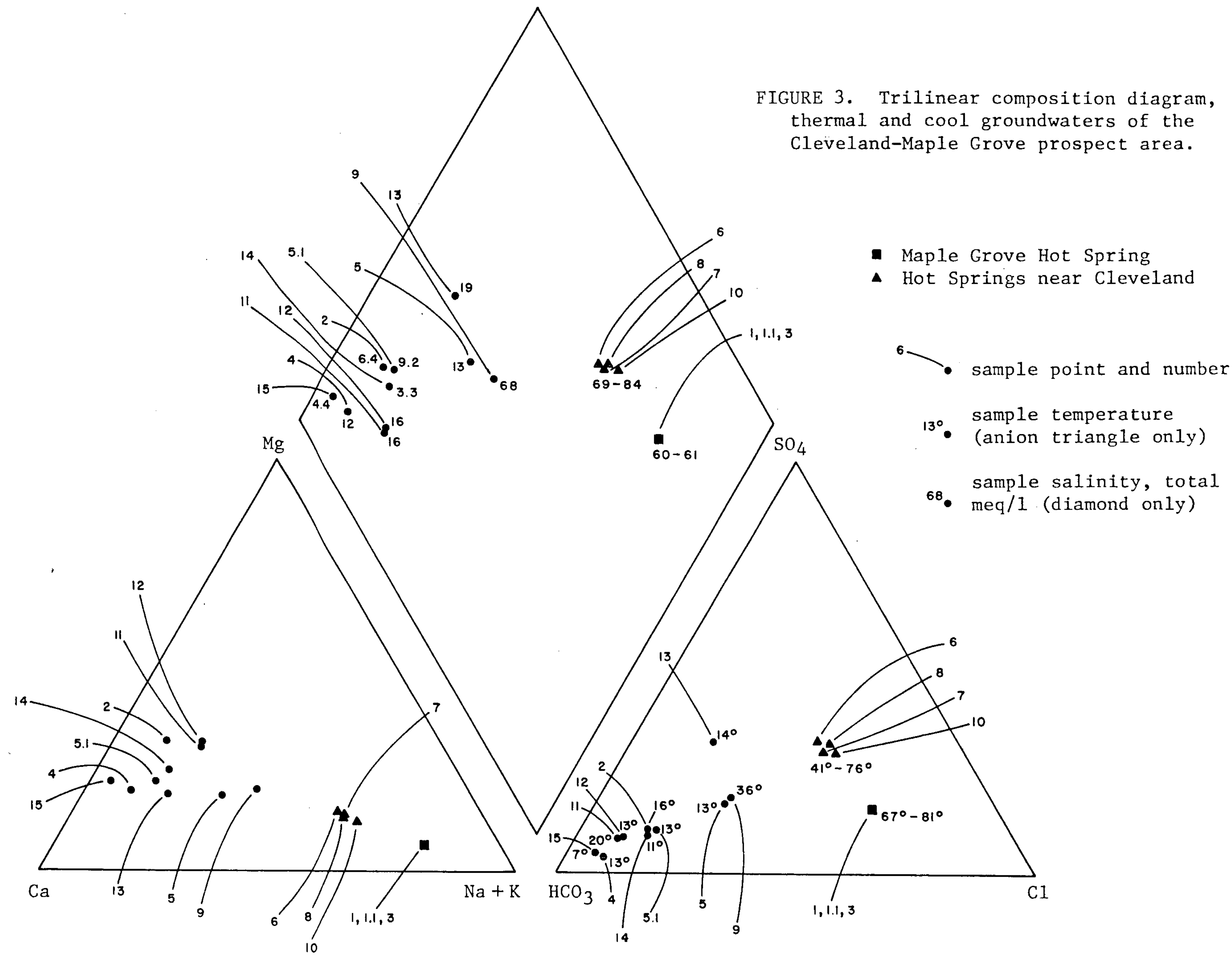

Table 5*

CHEMICAL ANALYSES OF THERMAL WATERS FROM THE NORTHERN CACHE VALLEY AREA

FRANKLIN COUNTY, IDAHO

(Chemical constituents in milligrams per liter)

Sample number, this study[1]	Spring or well identification number & name	Temperature (ºC)	Well depth below land surface (meters)	Discharge (l/min)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Total alkalinity as bicarbonate ion (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Phosphate (PO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Ammonia (NH_3)	Specific conductance (Cond)	Field (pH)	Total dissolved solids	Sodium adsorption ratio (SAR)
	Cleveland H.S.																					
–	12S-40E-36acd1S	35		10	54	265.0	68.0	563	127.0	704.0	0.0	788.0	0.01	632.0	2.2	0.93	3.40	1.3	4,149	6.6	3,020	8.0
6.0	36aca1S	33		10	52	259.0	64.0	517	137.0	704.0	0.0	755.0	0.01	633.0	1.9	0.37	3.40	1.2	4,199	6.6	2,932	7.5
8.0	12S-41E-31cac1S	66		20	60	208.0	50.0	458	98.0	718.0	0.0	533.0	0.01	532.0	1.9	0.11	2.80	1.6	3,229	6.4	2,499	7.4
10.0	31cdb1S	61		50	64	178.0	50.0	460	102.0	576.0	0.0	530.0	0.01	530.0	1.9	0.21	2.90	1.5	3,379	6.5	2,324	7.9
7.0	31cca1S	56		10	63	172.0	50.0	460	100.0	583.0	0.0	538.0	0.01	532.0	1.9	0.76	2.80	0.8	3,189	6.5	2,335	7.9
	Maple Grove Hot Springs																					
–	13S-41E-7aca1S	78		20	84	85.0	30.0	492	82.0	494.0	0.0	256.0	0.01	596.0	1.1	0.07	2.30	1.4	2,909	6.6	1,953	11.7
–	7aca2S	72		100	85	93.0	29.0	501	82.0	495.0	0.0	261.0	0.02	601.0	1.1	0.12	2.30	1.3	2,979	6.8	1,980	11.6
1.0, 1.1	7aca3S	60		935	86	93.0	25.0	492	80.0	494.0	0.0	251.0	0.01	584.0	1.0	0.06	2.30	0.9	2,899	6.8	1,939	11.7
	Ben Meek Well																					
	14S-39E-36ada1	40	12	-	89	24.0	6.6	368	22.0	513.0	0.0	13.0	0.01	322.0	9.6	0.10	0.58	1.1	1,809	6.9	1,246	17.2
	Battle Creek Hot Springs																					
	15S-39E-8bcd1S	82		50	109	174.0	19.0	3,161	552.0	696.0	0.0	35.0	0.01	5,241.0	6.0	0.11	3.50	7.6	16,619	6.7	9,326	60.8
	8bdc2S	43		2,160	107	166.0	15.0	3,071	535.0	697.0	0.0	29.0	0.01	5,048.0	6.0	0.42	3.40	7.3	15,439	6.5	9,026	61.2
	8bdc3S	81		-	109	162.0	19.0	3,053	533.0	757.0	0.0	37.0	0.01	5,034.0	6.0	0.28	3.60	7.2	15,949	6.5	9,062	60.5
	8bdc4S	84		5	97	215.0	24.0	4,184	686.0	610.0	0.0	33.0	0.01	6,967.0	6.4	0.06	5.30	10.0	18,479	6.8	12,033	72.2
	Squaw Hot Springs Well																					
	15S-39E-17bcd1	84	7	115	124	279.0	24.0	4,368	782.0	791.0	0.0	35.0	0.02	7,398.0	4.3	0.12	4.30	8.1	20,459	6.5	12,895	67.4
	Squaw Hot Springs																					
	15S-39E-17acc1S	73		450	126	241.0	26.0	3,844	533.0	866.0	0.0	23.0	0.02	6,396.0	4.8	0.06	4.60	9.7	16,859	6.6	11,396	62.8
	17bcd1S	69		140	126	135.0	23.0	4,184	708.0	816.0	0.0	27.0	0.03	6,877.0	4.3	0.16	4.20	7.3	20,519	6.5	12,062	87.6
	Myron Fonnesbeck Well																					
	16S-38E-24acd1	23	157	4,165	74	78.0	27.0	68	18.0	418.0	0.0	4.3	0.03	91.0	0.5	0.08	0.42	0.1	889	6.8	686	1.7

Analyses by: U.S. Bureau of Reclamation

[1]Approximate correlation, based upon map coordinates

*from Mitchell (1976)

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most saline. Therefore such mixing appears uncertain unless the water has been concentrated by evaporation or the thermal component is more saline than Maple Grove water. Waters which appear somewhat more likely to be mixed are the warm spring at The Mound (sample 9) and cool spring sample 5 collected near Cleveland Hot Spring.

The Cleveland and Maple Grove waters are sufficiently similar that a common history at depth is likely. The composition is probably controlled mostly by circulation through limestones and dolomites of the Paleozoic section.

The waters could reside in aquifers of such rocks at depth, but alternatively could reside mostly in lower Cambrian rocks such as the Brigham quartzite, but also circulate through carbonate strata.

Geothermometry and Interpretation

Table 4 shows the results of applying silica and cation geothermometers to the samples. Of principal interest herein are the quartz, conductive (QTZC), chalcedony (CHAL), Na-K-Ca (NKC) and Mg corrected Na-K-Ca (CMG) temperatures. The remaining geothermometers are most probably inapplicable in consideration of the compositions of probably aquifer rocks, indicated temperature ranges and surface conditions at the springs.

Basic cation temperatures (NKC) of the thermal waters are about 210° to 230°C whereas silica temperatures are only about 60° to 85°C for chalcedony and 90° to 115°C for quartz. The large difference must be explained either on the basis of a mixed origin for the waters or by regarding at least one of the geothermometers as inapplicable.

Points in favor of and against each alternative include the following:

Alternative	In Favor
Mixing	--Quartz and cation temperatures above orifice temperature at springs with high flow rate (significant conductive cooling during ascent from depth unlikely).
	Against
	--High Mg in thermal waters, generally exceeding levels in cool groundwaters of the area.

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Alternative	Against
Mixing	--Silica mixing model on the basis of quartz solubility predicts a maximum of about 140°C at depth (175°C with silica data of Mitchell) yet extension of suggested mixing ratios to calculation of likely deep fluid cation composition gives much higher basic Na-K-Ca temperatures (≳240°C).
	--Chalcedony temperatures agree well with orifice temperatures, particularly at springs with high flow rates, unlikely to have cooled significantly by conduction or to have re-equilibrated with surrounding rocks during ascent.
Na-K-Ca geothermometer inapplicable	**In Favor**
	--Connate waters from marine sediments may have spuriously high Na-K-Ca temperatures.
	--Mg-correction to Na-K-Ca temperature gives close agreement with orifice temperature.
	--Travertine deposits usually are considered to indicate moderate temperatures at depth.
	--The stratigraphic section lacks crystalline feldspar-bearing rocks and is mostly marine sediments, yet feldspar-water equilibria form the theoretical basis for the Na-K-Ca geothermometer.

The Mg-correction to the Na-K-Ca geothermomether is a relatively new development and somewhat controversial. It is totally empirical and, we believe, best regarded as a semi-quantitative indicator of over-estimation of temperature by the uncorrected Na-K-Ca geothermometer, although here is does produce excellent agreement between calculated and observed orifice temperatures. The basis of the correction is the observation that, worldwide, thermal waters become increasingly depleted in Mg relative to Ca and K at increasing

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aquifer temperatures. Thermal waters with several thousand mg/l or less total dissolved solids typically have only several mg/l Mg, at most, when above 150°C.

Figure 4 shows silica versus enthalpy for all samples, plus a mixing line illustrating a predicted 140°C at depth for the thermal waters if the solubility of quartz controls silica. Enthalpy is essentially equal to temperature in the range considered. The solubility curve for chalcedony is also shown, drawn from the curve given by the chalcedony geothermometer. Chalcedony is actually a mixture of microcrystalline quartz with hydrated and amorphous silica. The solubility curve is probably not unique but illustrates the greater solubility of chalcedonitic forms of silica over that of quartz. Although quartz is believed to control silica solubility at temperatures above 100° to 150°C, published studies of low to moderate temperature thermal waters, and our own proprietary studies, indicate that in and below 100° to 150°C range, observed levels of dissolved silica often agree more closely with the solubility of chalcedony.

Considering the facts and rationalizations above, our estimate of the most probable minimum temperature of rock-water equilibration at depth is 85°C to 100°C, the maximum chalcedony temperatures indicated by silica measured for this study and by Mitchell (1976), respectively. The basic cation geothermometer is considered invalid or highly inaccurate. Temperatures above 85°C to 100°C appear less likely, but cannot be discounted. Silica mixing based upon quartz solubility allows maxima from about 140°C to 180°C, but still requires the cation geothermometer to be invalid, which becomes somewhat less likely at higher aquifer temperatures. Temperatures above 140°C to 180°C are still less likely and would appear possible only if the waters are losing silica after mixing and prior to issuing at the surface, which is not expected in view of the high flow rates.

Comparison with Preston Area

Table 5, reproduced from Mitchell (1976) includes analyses of thermal waters from Battle Creek Hot Springs and Squaw Hot Springs and Well in the Preston area, south of the Maple Grove prospect. These waters are distinguished by having salinities 4 to 6 times greater than the Maple Grove area waters, due principally to a large enrichment in Na-Cl. Other dissolved species are lower, higher, and about the same. Among the major ions, K is notably higher and SO_4 notably lower. Different aquifer rocks are probably involved in these systems, and the high Na-Cl suggests

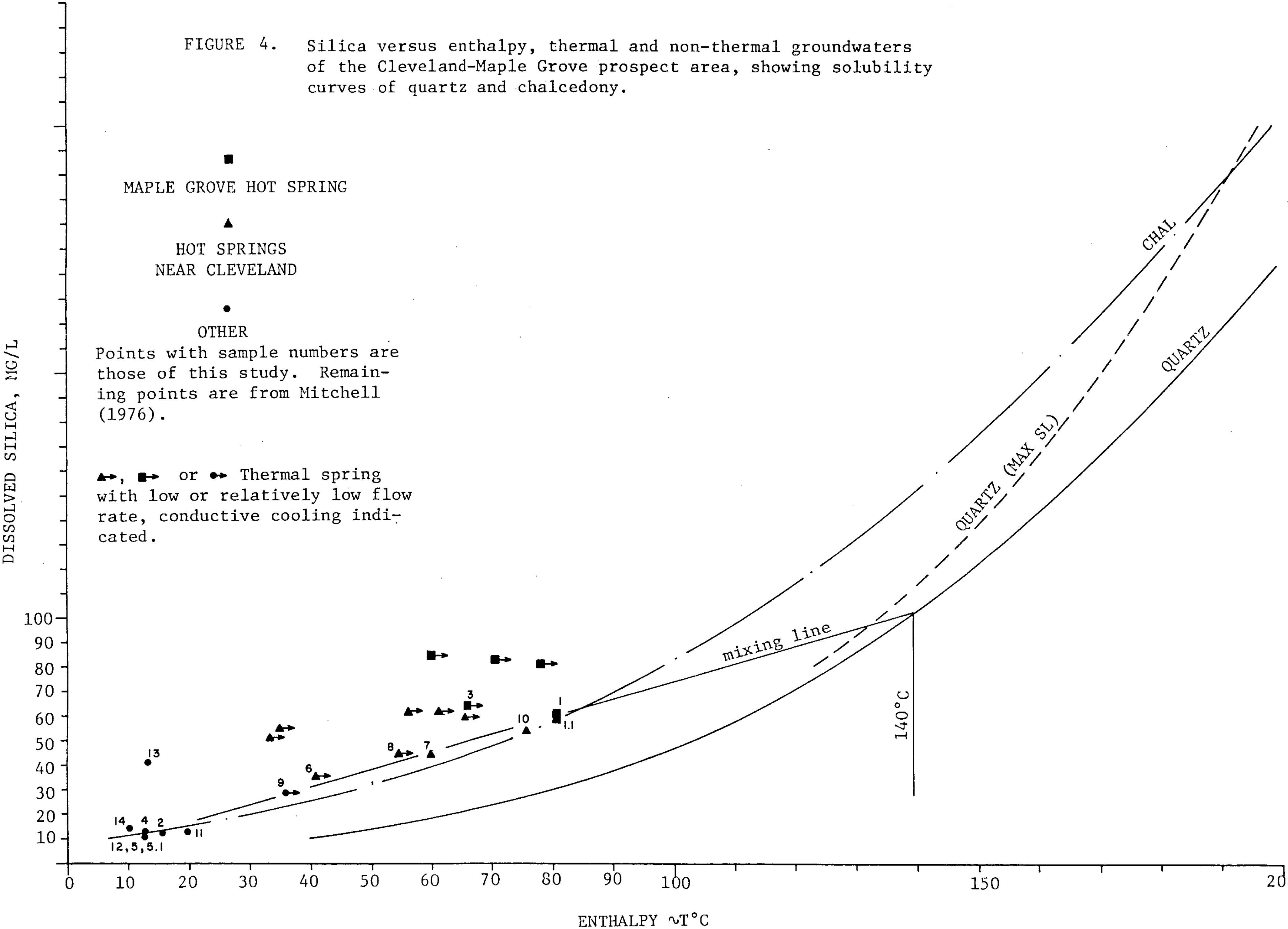

FIGURE 4. Silica versus enthalpy, thermal and non-thermal groundwaters of the Cleveland-Maple Grove prospect area, showing solubility curves of quartz and chalcedony.

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possible circulation through halite-bearing marine evaporites, but high levels of Ca and Mg also suggest contact with carbonates at moderate temperatures. Battle Creek and Squaw Hot Springs and Well have associated travertine deposits.

Silica geothermometry gives quartz (conductive) temperatures of 140 to 150°C and chalcedony temperatures of 115°C to 125°C at Battle Creek Hot Springs and Squaw Hot Springs and Well. If Mitchell's (1976) SiO_2 data are systematically too high by 10 to 20 mg/l (see above) these estimates would lower to about 130° to 140°C for quartz and 105° to 115°C at corrected levels. Na-K-Ca temperatures are 255°C to 260°C, which lower to about 210° to 220°C with application of the Mg-correction.

The silica geothermometers here are notable in that both quartz and chalcedony temperatures are significantly above orifice temperatures, and this is true in spite of high flow rates which make unlikely conductive cooling of the waters during ascent from depth. Conventional application of geothermometry thus requires considering these waters to be mixed. Construction of a definite silica mixing model is not possible herein due to lack of good data regarding the probable SiO_2 levels in a cool mixing component. The chemical analysis of the Myron Fonnesbeck Well (table 5) may be a guide. This gives predicted deep fluid temperatures of about 170°C to 190°C, assuming a deep fluid in equilibrium with quartz, dropping to about 130° to 150°C, assuming a deep fluid in equilibrium with chalcedony. Lower silica levels in the cold mixing component would raise these estimates considerably.

The Na-K-Ca temperatures, as at Maple Grove, may be invalid due to the presence of evaporites or connate waters in these systems. We believe that most likely this is the case, particularly in view of the high Ca and Mg in these waters.

The Preston area waters are probably higher temperature at depth than the Maple Grove area waters, but temperatures at depth are hard to estimate due to uncertainties regarding mixing. Minima at depth of at least 130° to 150°C appear likely, and higher temperatures appear possible. Deposition of travertine from the waters reduces the likelihood of temperatures much in excess of 100°C. High temperature waters with considerable Ca and Mg and which tend to deposit carbonates are known (e.g., at Mexicali, Cerro Prieto, Mexico), so the possibilty of temperatures in the Battle Creek and Squaw systems at levels indicated by the Na-K-Ca geothermometers remains real.

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JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

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GeothermEx, Inc. 901 MENDOCINO AVE.
BERKELEY, CA. 94707

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

APPENDIX A

DESCRIPTION AND EVALUATION OF PROPOSED TEMPERATURE GRADIENT HOLE SITES, CLEVELAND-MAPLE GROVE PROSPECT, IDAHO

GeothermEx, Inc. 901 MENDOCINO AVE. BERKELEY, CA. 94707

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

Two groups of sites have been proposed for 300-foot temperature gradient holes in the Cleveland-Maple Grove area. The following discussion is based on the geologic map, plate 3 and the site location maps 2 and 3, in the accompanying geological and geochemical evaluation of the area.

The first group of sites, numbered 1 through 9, were selected by Sunedco and Supron to evaluate the shallow gradients on large acreage blocks and to provide regional background data for outlining the geothermal anomalies in the area. The second numbered 10 through 14, have been recommended by GeothermEx as a result of the accompanying geological and geochemical evaluation. They have been proposed as supplements to the original program or possible replacements for one or more of the original sites. The sites proposed by GeothermEx are for the purposes of providing subsurface gradient data within the general area of thermal or mineral springs, and the vicinity of important areas of faulting which may be associated with the thermal systems. The present lease holdings in which Sunedco has an interest are not all known to GeothermEx and some of the sites may not be accessible and of direct interest.

The purpose of this review is to describe briefly the surface conditions and character of the subsurface section likely to be encountered at each locality. It is hoped that this discussion will be useful in assigning priorities to sites and anticipating equipment needs and drilling problems which may occur.

Particular aspects of this program are uncertain. These include the drilling costs and problems which may occur in the Quaternary aquifer gravels and in the very hard Cambrian rocks, particularly the Brigham Quartzite. The topographic effect on gradients in holes near Oneida Narrows also needs to be assessed. In view of these uncertainties, the program should be flexible and continuously evaluated to determine if useful results are being obtained.

TEMPERATURE GRADIENT HOLE NO. 1

Location: Approximately in N.W. quarter, N.W. quarter of Section 25, T. 12 S., R. 40 E.

Access and Surface Conditions: The main access road which follows the Cleveland Irrigation Canal is a 2-lane paved road, in good condition. Approximately 0.3 mile southeast of the Cleveland Cemetary turnoff, a steep, winding, unpaved road approaches the

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

proposed site. This road may require some grading. There are level areas for setting up, and water for drilling can be obtained from the Bear River or from local springs.

Subsurface Conditions: Pleistocene lake beds are present at the surface of this site. They consist of poorly consolidated sands, silts, clays and gravels in unknown proportions. Sands and gravels are likely to be high-yielding cold water aquifers. The thickness of this material is unknown, but may exceed 300 feet. If bedrock is encountered, it is likely to be medium-bedded, hard, highly fractured Brigham Quartzite, of Cambrian age. Nearby outcrops of this unit are dipping 30^{o} to 50^{o} to the northeast. Faulting may be present in the pre-Quaternary rocks. A concealed northeast-trending fault, if extended 0.5 mile southwestward, would pass through the approximate location of this site. This coincides with the Treasureton-Lineament-Bear River Range boundary fault zone.

Conclusions: This site may encounter water flows in Quaternary sediments and slow penetration rates in Brigham Quartzite. Otherwise the site should provide useful data in an area in which control is needed.

TEMPERATURE GRADIENT HOLE NO. 2

Location: Approximately N.E. quarter, of the S.W. quarter of Section 36, T. 12 S., R. 40 E.

Access and Surface Conditions: The access road, which joins State Highway 34 near the center of Section 36, is unpaved but in good condition, and would probably not require grading. There is one unlocked, unsigned fence to pass through. The area of the proposed site is level, and water is abundant in rivers and streams nearby.

Subsurface Conditions: A major fault zone is likely to be present beneath the alluvium immediately north of the topographic slope in the southern part of Section 36. If the hole is drilled to the north of the 5,000 foot contour, it may encounter a significant thickness of recent river silt, sand and gravel, possible tufa, and Pleistocene sands and gravels, perhaps to total depth. These sediments may contain high-yielding aquifers. If bedrock is reached here, it could be either Brigham quartzite or Cambrian limestone, depending on the fault zone displacement. The fault itself may be a conduit for thermal or mineralized water. If the hole is drilled south of the 5,000 foot contour, it may encounter a thin soil and quartzite float cover overlying the hard, fractured Brigham Quartzite. The attitude of bedding in the quartzite is unknown but it may dip

GeothermEx, Inc. 901 MENDOCINO AVE.
BERKELEY, CA. 94707

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

30° to 50° to the northeast.

Conclusions: This hole should be drilled to the north of the topographic slope in an attempt to drill near the proposed fault, but to avoid drilling in the Brigham Quartzite. Cold or warm groundwater aquifers could be encountered here.

TEMPERATURE GRADIENT HOLE NO. 3

Location: Near the center of the west half of Section 8, T. 13 S., R. 41 E.

Access and Surface Conditions: The site can be reached either by the road which heads southeast from Maple Grove Hot Springs, slightly north of the springs, or from a road heading northwest from State Highway 36, in the northeast corner of Section 17. The road is unpaved, has washed-out areas where streams intercept it, gullies on the shoulders, and areas where rockfalls occur. The road was traveled without 4-wheel drive, but may require grading for drill rig access. The proposed site is fairly level, and water for drilling is available in local streams.

Subsurface Conditions: Pleistocene gravels a few feet thick, made up of silt and bedrock fragments are present at the surface around this site. Beneath these, drilling should encounter hard fractured Brigham Quartzites. The Cambrian quartzites in this area dip at about 20° to the northeast. No faults have been mapped in the immediate vicinity and the fault which appears to localize Maple Grove Hot Springs is about one-half mile east of the site.

Conclusions: It may be difficult to obtain a significant gradient in a 300-foot hole, in this topographic setting. Bedrock drilling would be hard and slow in the Brigham Quartzite. Cold ground water feeding local perched springs would probably depress temperatures and temperature gradients.

TEMPERATURE GRADIENT HOLE NO. 4

Location: Approximately the S.E. quarter of the S.W. quarter, Section 17, T. 13 S., R. 41 E.

Access and Surface Conditions: This location is accessible via a farm road heading northwest from State Highway 36, near the boundary of sections 8 and 17. The site would be inaccessible in wet weather due to boggy conditions.

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MURRAY C. GARDNER

Subsurface Conditions: This site is located on colluvium or stream sediments made up of poorly-sorted gravels and silts with scattered blocks of quartzite. The bedrock formation is the Brigham Quartzite and it is likely to be encountered at shallow depth. The quartzite is medium-bedded, jointed and hard. It dips to the northeast at 20° to 30°. No faulting has been mapped in the immediate vicinity, but minor faulting could be present under the Quaternary cover. This site is located along a northwest trend which includes the thermal spring areas and the Portneuf Range Boundary fault zone.

Conclusions: This site is remote from any reported thermal or mineral springs, it does not appear to be located on a major fault, and it is likely to encounter hard rocks and slow drilling. However, it might yield useful information relative to its position along the northwest trend.

TEMPERATURE GRADIENT HOLE NO. 5

Location: Approximately in the N.E. quarter of the N.W. quarter of Section 24, T. 13 S., R. 40 E.

Access and Surface Conditions: This site can be reached either by driving northeast from Oneida Station along the Oneida Narrow Reservoir, or by driving southwest from Maple Grove Hot Springs. The road is unpaved, with occasional washouts from streams and gullies, but can be traveled without 4-wheel drive, and would probably not require any grading. The site location is level, but is adjacent to a picnic area with tables and benches, and may be part of a state or county recreational area.

Subsurface Conditions: Alluvium, made up in part, of coarse fan deposits, is present at this site to depths of at least several tens of feet. The underlying bedrock unit is hard, fractured, Brigham Quartzite. The dip in this formation is from 20° to 40° toward the east. No faults have been mapped in the vicinity of this formation. No thermal fractures are known in the area.

Conclusions: Drilling at this site may be difficult due both to the fan material and the quartzite. However, a hole here is likely to show a more representative gradient profile than at sites 7 and 8, drilled near the gorge but far above the floor.

TEMPERATURE GRADIENT HOLE NO. 6

Location: Approximately the N.W. quarter of the N.W. quarter of Section 2, T. 13 S., R. 40 E.

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JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

Access and Surface Conditions: The Cleveland Irrigation Canal Road is a good access road. The site is located in a residential area, and the hole may have to be drilled in someone's backyard. Otherwise, there are level areas for setting up, water is readily available, and access is not a problem.

Subsurface Conditions: The section in this site area consists of recent stream sediments underlain by hard, fractured Brigham Quartzite. Quaternary sediments cover any faults at the site. However, several faults trend toward Cottonwood Creek and may underlie the drainage.

Conclusions: The subsurface conditions are uncertain at this site. Difficult drilling may be encountered in Quaternary gravels and Brigham Quartzite, if the latter is reached. The gravels may be cold water aquifers.

TEMPERATURE GRADIENT HOLE NO. 7

Location: N.E. quarter of the N.E. quarter of Section 11, T. 13 S., R. 40 E.

Access and Surface Conditions: This site is located approximately one mile west of Oneida Narrows gorge, at an elevation of about 500 feet above the river. The site is reached by a dirt road which heads southeast from Highway 34 near the intersection of the highway with the power lines in Section 3. The road is unpaved, but was driveable without 4-wheel drive. The road gets boggy in certain areas, due to runoff and streams, so would best be drilled in dry weather.

Subsurface Conditions: Poorly-sorted gravel and blocks of bedrock in a silty matrix make up an old Pleistocene surficial deposit at this locality. This material is probably a few tens of feet thick. It overlies hard, fractured Brigham Quartzite. This formation dips to the northeast at about 30°. This site was originally sited along a concealed fault, approximately 0.25 mile southeast of its present location.

Conclusions: Drilling at this site may be slow in the quartzite. Lost circulation may occur in fractures. The effect of the topography associated with the nearby gorge will have to be ascertained relative to the temperature gradient.

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

TEMPERATURE GRADIENT HOLE NO. 8

Location: Approximately the S.W. quarter of the N.W. quarter of Section 14, T. 13 S., R. 40 E.

Access and Surface Conditions: This site is slightly less than one mile west and northwest of the steep topographic gradient descending to the Bear River in the Oneida Narrows Gorge. The elevation difference between the site and the river is about 1,100 feet. The access road is an unpaved road heading southeast, then northeast from State Highway 34, in the southeast quarter of Section 17. The road was traveled without 4-wheel drive to the center of Section 15, where runoff had created gullies, and beyond which travel was by foot. The site appeared level, with a cover of grassy soil strewn with occasional quartzite boulders and cobbles. The road might require some grading and the rig and/or water truck might require towing assistance, especially if the roads are still wet.

Subsurface Conditions: A hole at this location will penetrate the Brigham Quartzite beneath a few feet of surface rubble and soil. As at other localities, this quartzite is medium-bedded, hard and fractured. It dips to the north-northeast between 35° and 40°. No faults have been mapped in the immediate vicinity of this site.

Conclusions: The topographic effect of the nearby gorge on temperature gradients will have to be considered at this site. Drilling will be slow in the quartzite and lost circulation may occur in fractures.

TEMPERATURE GRADIENT HOLE NO. 9

Location: Near the center of the north quarter of Section 27, T. 13 S., R. 40 E.

Access and Surface Conditions: This site is located near the edge of the steep topographic slope descending over 1,200 feet to the Bear River. The access is via an unpaved road heading southeast from State Highway 34, near the soutwest corner of Section 20. The road was traveled to near the center of Section 28 without a 4-wheel drive vehicle, then walked to the proposed drillsite, because of the gullies and runoff. Grading and possibly towing might be required to move in the drill-rig and water truck, especially if conditions are wet. The site is fairly level, and covered with grassy soil mixed with scattered cobbles and boulders of quartzite.

Subsurface Conditions: A thin mantle of colluvium made up of gravel

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

and silt may overlie the Tertiary Salt Lake Formation at this site. The Salt Lake Formation is not well-exposed in this area, but it is believed to consist mainly of slightly to moderately indurated, light green to gray, tuffaceous and calcareous claystone and siltstone. Various amounts of sandstone, pebble conglomerate and limestone may also be present. A prominent hematite-stained zone occurs at the base of the formation. This formation contains few porous units and does not support fracture as readily as the underlying Paleozoic rocks. Thus, lost circulation problems appear less likely to occur here than in the other upland sites, particularly #7 and #8. Penetration rates in this type of rock are likely to be good. Water sensitive clays may be present.

The attitude of these rocks is unknown but dips in the 25° to 50° range are probable. No faults have been mapped in the immediate vicinity of the site.

Conclusions: This is the only hole proposed here which is likely to penetrate into the Salt Lake Formation. Drilling conditions should be good in this unit. However, the topographic effect of the adjacent deep gorge may strongly influence the gradient in a hole only 300 feet deep.

TEMPERATURE GRADIENT HOLE NO. 10

Location: Near the center of the N.E. quarter of Section 24, T. 12 S., R. 40 E.

Access and Surface Conditions: Access to this site on the south side of the large tufa mound is by means of a poor quality farm trail across cultivated land. The surface conditions may depend on whether the land is under cultivation at the time of drilling.

Subsurface Conditions: The large tufa mound at this locality is the site of a nearly defunct mineral spring which is slightly thermal. A gradient hole here should indicate whether an anomaly is present in the subsurface. The section at this site is likely to be entirely unconsolidated Quaternary sediments, including tufa, sand, silt, clay and gravel of lacustrine origin. Structurally, the mound is close to the intersection of two major fault systems, one trending northwest along the boundary between the Portneuf Range and Gentile Valley, and the other trending north along the west side of the Bear River Range.

Drilling conditions should be easy, except that sands and gravels in this section may be high yield aquifers.

GeothermEx, Inc. 901 MENDOCINO AVE. BERKELEY, CA. 94707

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

TEMPERATURE GRADIENT HOLE NO. 11

Location: Approximately the S.W. quarter of the S.E. quarter of Section 19, T. 12 S., R. 41 E.

Access and Surface Conditions: This site is located north of the intersection of State Highway 34 and a residential access road along the north side of Williams Creek. The land adjacent to the road is cultivated and the site likely to make the least disturbance is at the eastern edge of the field, along the road.

Subsurface Conditions: This site is located on Quaternary lake beds consisting of gravel, sand and silt of unknown thickness. Much of the surface in this area is strewn with quartzite cobbles and small boulders which are either lag material derived from the washing of the underlying lake beds or are a fan-like deposits at the surface. They will make drilling difficult. If a 300-foot deep hole can reach pre-Cenozoic rocks, they are likely to be mudstone, claystone or limestone of the upper part of the Cambrian or lower Ordovician section.

Several north to northeast-trending faults in bedrock trend toward this site, but their location in the site area is uncertain due to the Quaternary cover. The site is approximately on trend with the Maple Grove and McGregor Ranch springs. Bright (1960) makes a reference to possible tufa deposits in Williams Creek but no specific location was given and they were not located in this study. The purpose of the hole is to investigate the gradient along this trend.

TEMPERATURE GRADIENT HOLE NO. 12

Location: Approximately N.E. quarter of N.W. quarter of Section 18, T. 12 S., R. 41 E.

Access and Surface Conditions: A site can be chosen near the access of the main canyon forest access road and State Highway 36. The land is cultivated in this vicinity and access might be difficult due to the soft, silty character of the soil. It is accessible only in dry weather.

Subsurface Conditions: This site has been located on the southwestward projection of the main fault bounding the west side of the Bear River Range in this area. The purpose of a hole here is to determine if this major fault zone is a factor in the distribution of thermal waters. The surface deposits are Quaternary lake beds of

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

unknown thickness. No quartzite lag deposits were noted here at the surface so that no especially difficult drilling conditions are anticipated. It is unlikely that a 300-foot hole would reach any older rocks. The Quaternary deposits consist of sand, silt, clay and gravel in unknown proportions. The sands and gravels may be water-bearing.

TEMPERATURE GRADIENT HOLE NO. 13

Location: Approximately N.E. quarter of N.E. quarter of Section 14, T. 12 S., R. 40 E.

Access and Surface Conditions: This site can be located adjacent to the unimproved farm trail shown on the topographic map. The road is surrounded by cultivated fields and passes through the yard of a farmhouse. It is a dry weather location. The owner might object to traffic through his yard.

Subsurface Conditions: This site has been selected to sample the projected extension of the major northwest trending fault zone separation the Portneuf Range from Gentile Valley and to assist in determining if this fault zone is of significance to the geothermal anomalies in the area. The surface here is covered by Pleistocene gravel, sand and silt of unknown thickness. There are no coarse lag deposits of quartzite cobbles and boulders at the surface here. If the hole penetrates this material it would intercept either Brigham Quartzite, Langston Formation shales or younger Cambrian limestones.

TEMPERATURE GRADIENT HOLE NO. 14

Location: Approximately center of the east line of the S.W. quarter of Section 31, T. 12 S., R. 41 E.

Access and Surface Conditions: This site is adjacent to an improved gravel road. The precise location depends on lease ownership and the landowners' permission. Some uncultivated land is available for a site. Local landowners seemed to be unfavorable to drilling in this vicinity.

Subsurface Conditions: The surface materials at this site are Quaternary sediments made up of gravel, sand, silt and tufa. The thickness of the Quaternary deposits is unknown and may exceed 300 feet. If bedrock is encountered it is most likely to be Brigham Quartzite or shales of the Ute and Langston Formations, or Blacksmith Limestone. Faulting is complex in this area and

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

the well may intercept the fault zone which contains the thermal mineral waters of the Maple Grove-McGregor Ranch trend. The purpose of a gradient hole at this site is to indicate whether the extensive tufa deposits are underlain by a higher temperature regime now sealed off near the surface.

GeothermEx, Inc. 901 MENDOCINO AVE.
BERKELEY, CA. 94707

JAMES B. KOENIG (415) 527-9876
MURRAY C. GARDNER

APPENDIX B

FIELD DATA SHEETS FROM

GEOCHEMICAL WATER SAMPLING

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 001

Date 4/28 - 29/80

Name SMG580 - MG3 (Maple Grove #3)

Time 1:00 pm; 8:56 am

Locaton SW ¼, NE ¼ Sec 7

T13S, R41E

Sampler B. Cox

Weather warm, sunny

Elevation ∿4930'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 81 Ground temp. °C 46-48 Air temp. °C 28

Fluid color colorless
Fluid clarity red sediment
Odor slight sulfur odor
Gas evolving yes

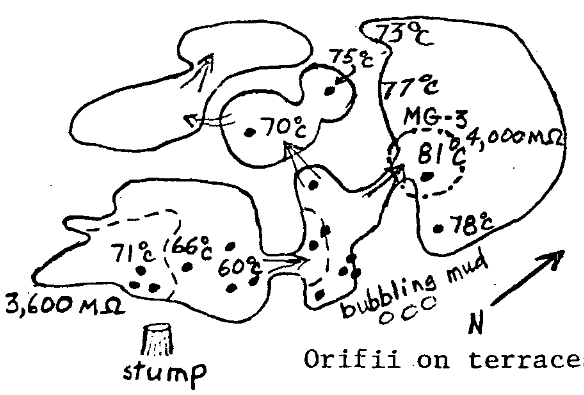
Discharge ∿60 lpm from orifice sampled; total discharge of pools & orifii - ∿900L/min
Well data: ______ pumped ______ flowing
depth ______ total
______ to water (water elev. ______)
______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	6.52-6.58		7 [X] paper [X] meter
Sp. Cond.	R	4500 um		meter
Cl		1300 mg/l		

Other Conditions:
Contamination orifice fills small pool; probably some rain contamination
Sinter deposits ______
Travertine deposits yes - terraces
Geologic setting Springs are seeping out of ground and out of fractures in Brigham Quartzite
Use of water Heating house and bathtub by pipes underneath house

Sketch:

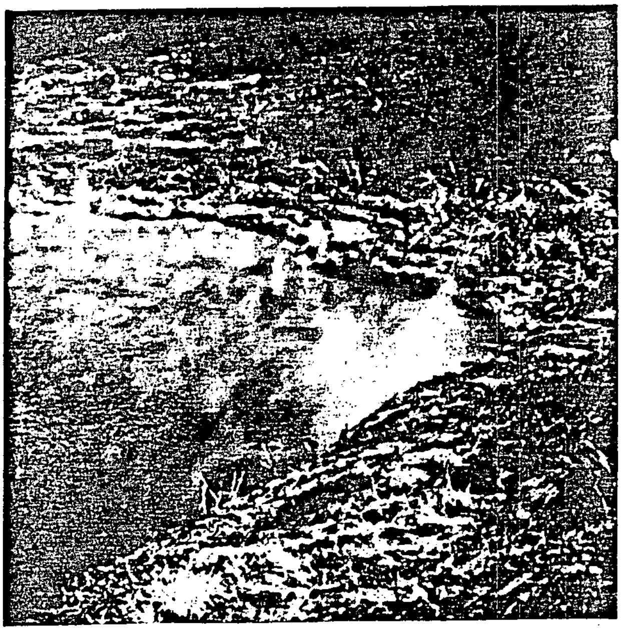


Orifii on terraces in foreground

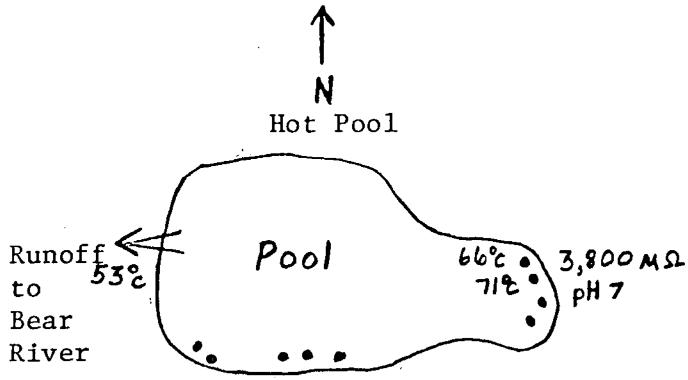
● = main orifice

◌ = sample point - hottest and most vigorous flow

Maple Grove Hot Springs
Looking NW; Bear River in background



EAST SIDE of hot pool -
MAPLE GROVE
150°-160°F at orifii



Hottest part of pool
is on East side

Total runoff to Bear River is ∿900 L/min. Temp. of outlet is 52°C-53°C. Ground temp. near outlet is 30°C-32°C.

Red algae is usually at hottest portions of springs and ponds.

CARETAKER: RANDY MOYER
P.O. Box 99
Thatcher, ID 83283

OWNER: CURRY LOCKETT
c/o N. American River
Expeditions
565 N. Main
Moab, UT 84532

Photo of discharge point into
Bear River

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 002

Date 4/29/80

Name SMG580 - M.G.C.S.

Time 10:30 a.m.

Locaton SE ¼, NE ¼ Sec 7

T13S, R41E

Sampler B. Cox

Weather sunny, warm

Elevation ∿5080'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 16 Ground temp. °C 15.5 Air temp. °C 21

Fluid color clear

Fluid clarity colorless

Odor ----

Gas evolving no

Discharge 9 lpm

Well data: ______ pumped ______ flowing

depth ______ total

______ to water (water elev. ______)

______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	7.20		[X] ∿6 paper [X] 7.20 meter
Sp. Cond.	R	325 um		meter
Cl		mg/l		

Other Conditions:

Contamination none apparent

Sinter deposits ----

Travertine deposits no

Geologic setting quartzite, limestones (probably is perched aquifer)

Use of water drinking water for house at Maple Grove. Spring issues into concrete pipe, then travels through plastic pipe

Sketch:

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 003 — Date 4/29/80

Name SMG580 - S.E.M.G. — Time 1:30 p.m.

Locaton NE ¼, SE ¼ Sec 7 — Sampler B. Cox

T13S, R41E — Weather warm, sunny

Elevation ~5080'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 67 Ground temp. °C -- Air temp. °C 21

Fluid color colorless

Fluid clarity sediment

Odor slight sulfur smell

Gas evolving trace

Discharge < 1 lpm from sample orifice, 9 L/min. from combined flow from 4 orifii

Well data: ______ pumped ______ flowing

depth ______ total

______ to water (water elev. ______)

______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	6.60		6 - 6.5 [X] paper; 6.60 [X] meter
Sp. Cond.	R	3800 um		meter
Cl		mg/l		

Other Conditions:

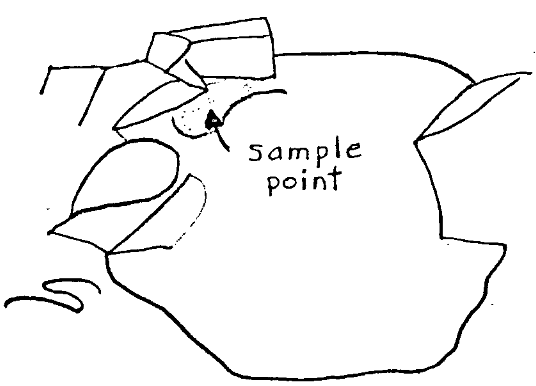
Contamination local run-off into pond

Sinter deposits ---

Travertine deposits minor

Geologic setting quartzite - rock falls of quartzite - at junction of 2 faults

Use of water none



Sketch:

SE of M.G. #1

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 004 | Date 4/29/80

Name SMG580 - C.S.S.E.MG | Time 3:00 p.m.

Locaton NE ¼, SW ¼ Sec 8 | Sampler B. Cox

T13S, R41E | Weather cloudy, windy

Elevation ~5520'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______
maybe diluted w/ runoff

Sample Data: Water temp. °C 13 Ground temp. °C 20 Air temp. °C 20

Fluid color colorless
Fluid clarity clear
Odor odorless
Gas evolving no

Discharge ~21 lpm

Well data: ______ pumped ______ flowing
depth ______ total
______ to water (water elev. ______)
______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

Component	Sample type	Level meas.	Where/when	Method/comments
pH	R	7.21		[X] paper 6-7 [X] meter 7.21
Sp. Cond.	R	640 um		meter 640 μΩ
Cl		mg/l		

Other Conditions:
Contamination Runoff - streams nearby
Sinter deposits -----
Travertine deposits -----
Geologic setting Quartzites, soil
Probably perched spring

Use of water ?

Sketch:

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 005A

Date 5/1/80

Name SMG-580 - CCS (Cleveland Cold Spring)

Time 1:30 p.m.

Locaton SE ¼ NE ¼ Sec 36

T12S R40E

Sampler B. Cox

Weather warm, windy

Elevation ~4940'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 13 Ground temp. °C 13 Air temp. °C 21

Fluid color colorless

Fluid clarity clear

Odor none

Gas evolving no

Discharge ______ lpm couldn't estimate because of runoff

Well data: ______ pumped ______ flowing

depth ______ total

______ to water (water elev. ______)

______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

Component	Sample type	Level meas.	Where/when	Method/comments
pH	R	7.0		[X] 6-7 paper [X] 7.0 meter
Sp. Cond.	R	680 um		meter
Cl		200 mg/l		

Other Conditions:

Contamination yes - runoff

Sinter deposits no

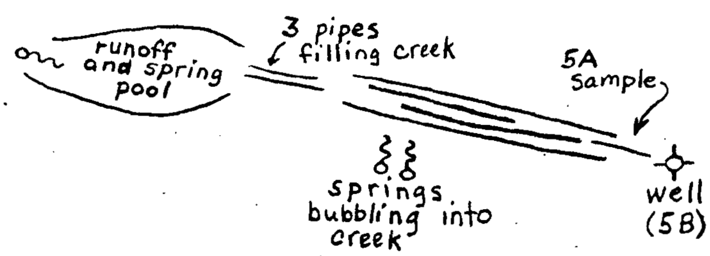
Travertine deposits no

Geologic setting springs in soil and alluvium below travertine terraces

Use of water drinking, irrigation

Sketch:

spring was sampled near well



FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 005B

Date 5/1/80

Name SMG580 - CCW (Cleveland Cold Well)

Time 1:30 p.m.

Locaton SE ¼, NE ¼ Sec 36

T12S, R40E

Sampler B. Cox

Weather warm, windy

Elevation ∿4940'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 13 Ground temp. °C 13 Air temp. °C 21

Fluid color colorless

Fluid clarity clear

Odor odorless

Gas evolving no

Discharge ______ 1pm

Well data: X pumped ______ flowing

depth 12' total

3' to water (water elev. ______)

6' to pump doesn't draw down, so good flow

Component--Sample type-Level meas.-Where/when--Method/comments:

Component	Sample type	Level meas.	Where/when	Method/comments
pH	R	6.9		[X] 6-7 paper [X] 6.9 meter
Sp. Cond.	R	498 um		meter
Cl		125 mg/l		

Other Conditions:

Contamination none, unless hose

Sinter deposits ---

Travertine deposits ---

Geologic setting Well is in creek bed. alluvium

Use of water Drinking water for house at Cleveland Hot Springs

Sketch:

Sampled from hose - well was not able to be sampled at wellhead.

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 006 | Date 5/1/80

Name SMG580 - CHS1 (Cleveland Hot Spring #1) | Time 1:45 pm

Locaton SE ¼, NE ¼ Sec 36 | Sampler B. Cox

T12S, R40E | Weather warm, windy

Elevation ~4950'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ________

Sample Data: Water temp. °C 41 Ground temp. °C 24 Air temp. °C 21

Fluid color colorless | Discharge ~50 lpm

Fluid clarity yellow sediment

Odor slight H_2S | Well data: ____ pumped ____ flowing

Gas evolving yes | depth ____ total

____ to water (water elev. ____)

____ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	6.61		[X] 6.87 paper [X] 6.61 meter
Sp. Cond.	R	4700 um		meter 4700 μΩ
Cl		mg/l		

Other Conditions:

Contamination Yes - pool - no access to orifices

Sinter deposits ----

Travertine deposits *See below

Geologic setting in an alluviated valley, on a travertine mound

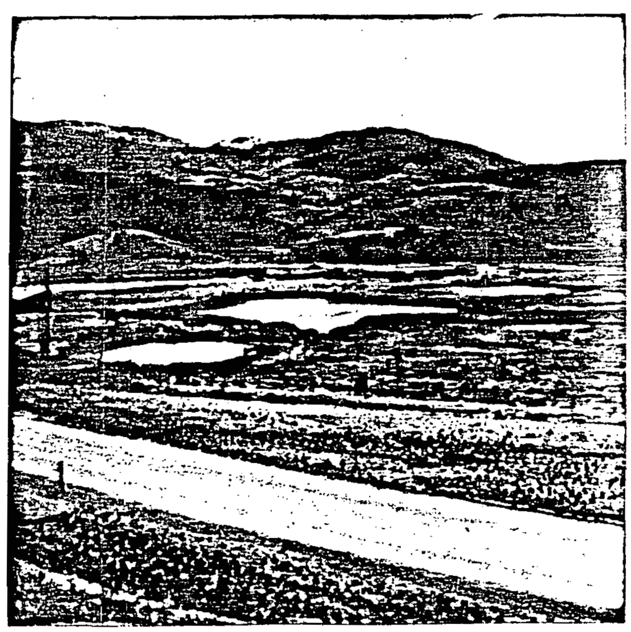
Use of water occasional recreational use

*Yes, on a travertine mound, but no way to tell if travertine is still being deposited -- it may be dissolving, according to Mitchell (1976).

Charlene and Bud ________, owners

Cleveland Pool #1 was sampled (Pool closest to highway and hottest pool). Orifii are in middle of pool w/ fairly vigorous bubbling. Passageway from first pool to second pool flows at ~54L / min. at 40°C, 4700 μΩ. From Pool #2 to #3, flow is ~63L/min., 33°C, 4850 μΩ. Pool #4 (not in picture, but to the right of #3) is 4900 μΩ, 33°C. No flow between 3 and 4.

Sketch:



Cleveland Hot Springs 1, 2, 3
5/1/80 Looking NE

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 007 | Date 5/1/80

Name SMG580 - Bear River #1 | Time 5:30 p.m.

Locaton NW ¼, SW ¼ Sec 31 | Sampler B. Cox

T12S, R41E | Weather windy, overcast

Elevation ~4900'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 60 Ground temp. °C 22 Air temp. °C 20

Fluid color colorless
Fluid clarity brownish sediment
Odor organic and slight H_2S smell
Gas evolving yes

Discharge > 200 lpm > 20 orifices - each around 150 ml/sec
Well data: ______ pumped ______ flowing
depth ______ total
______ to water (water elev. ______)
______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	6.20		[X] paper 7 [X] meter 6.20
Sp. Cond.	R	3900-4200um		meter 3900-4200
Cl		1050 mg/1		

Other Conditions:
Contamination runoff of other springs & creek
Sinter deposits ----
Travertine deposits yes
Geologic setting alluvium valley

Use of water none
fish like it

area is very swampy, marshy

Sketch:

sample point

Bear River Hot Spring #1

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 008

Date 5/2/80

Name SMG580 - Bear River #3

Time 7:50 a.m.

Locaton NW ¼, SW ¼ Sec 31

T12S, R41E

Sampler B. Cox

Weather cloudy, calm

Elevation ∿4900'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 54 Ground temp. °C 21 Air temp. °C 12

Fluid color colorless
Fluid clarity brown sediment
Odor H_2S, organic smells
Gas evolving yes

Discharge ∿130 lpm from outflow of spring > 20 orifices, vigorous bubbling

Well data: ______ pumped ______ flowing
depth ______ total
______ to water (water elev. ______)
______ to pump

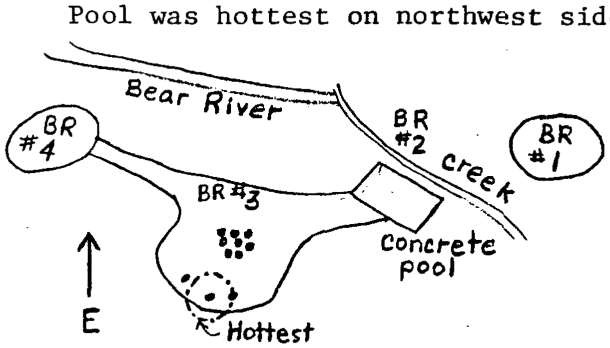
Component--Sample type-Level meas.-Where/when--Method/comments: pH paper got wet

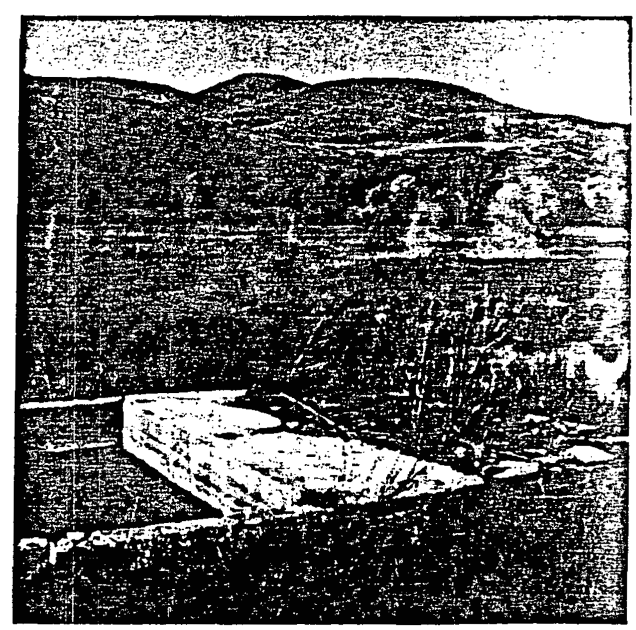
pH	R	6.37		☐ paper ☒ meter 6.37
Sp. Cond.	R	4600 um		meter 4600 μΩ
Cl	22 drops =	1100 mg/l		

Other Conditions:
Contamination boggy - probable river contamination
Sinter deposits ---
Travertine deposits none visible
Geologic setting springs oozing out of marsh - clay and organic deposit and soil
Use of water ----

Pool was hottest on northwest side

Sketch:





Bear River Creek #2
(#1 in background)

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 009 Date 5/2/80

Name SMG580 - The Mound Time noon - 1 p.m.

Locaton SW ¼, SE ¼ Sec 13 Sampler B. Cox

T12S, R40E Weather sunny w/clouds, wind

Elevation ~5040'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 36 Ground temp. °C ? Air temp. °C 24

Fluid color colorless Discharge 3-5 lpm
Fluid clarity clear w/ algae
Odor H_2S - organic smells Well data: ______ pumped ______ flowing
Gas evolving no depth ______ total
______ to water (water elev. ______)
______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	6.28		☐ paper ☒ 6.28 meter
Sp. Cond.	R	3280 um		meter 3280 µΩ
Cl	16 drops =	800 mg/l		

Other Conditions:
Contamination stagnant pool
Sinter deposits ---
Travertine deposits On a travertine mound
Geologic setting On a vegetated mound near a white, unvegetated mound

Use of water ---

Note: The Mound leases were sold to Sysron while I was in area

Sketch:

The Mound Warm Spring looking northerly

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 010

Date 5/2/80

Name SMG580 - Cow Hot Springs

Time 2:17 p.m.

Locaton SW ¼, SW ¼ Sec 31

T12S, R41E

Sampler B. Cox

Weather cold, windy, thunderclouds

Elevation ~4950'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 76 (maximum) Ground temp. °C ? Air temp. °C 17

Fluid color colorless

Discharge ~9 lpm at orifice sampled.

Fluid clarity clear w/ minor sediment

> 60 orifii - fairly vigorous

Odor slight H_2S smell

Well data: ______ pumped ______ flowing

Gas evolving yes

depth ______ total

other orifii varied from 64°C to 66°C

______ to water (water elev. ______)

______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	6.40		☐ paper ☒ meter 6.40
Sp. Cond.	R	3850 um		meter 3850 µΩ
Cl		mg/l		

Other Conditions:

Contamination Pools - so some rainwater

Sinter deposits ---

Travertine deposits yes - on a mound

Geologic setting Travertine mound - soil and alluvium

Use of water Hot spring is in a cow pasture

Note: There used to be a well in the backyard of the house, which showed warm temperatures at 12' depth. It is now filled in.

Sketch:

Cow Pasture Hot Spring
Note numerous orifii
Circled area is sample point

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 011 — Date 5/3/80

Name SMG580 - McGregor Warm Spring — Time 8:52

Locaton NE ¼ NW ¼ Sec 31 — Sampler B. Cox

T12S, R41E — Weather cold, cloudy slight wind

Elevation 4960'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 20 Ground temp. °C 16 Air temp. °C 12

Fluid color colored
Fluid clarity clear
Odor none
Gas evolving no

Discharge 180-240 lpm from combined flow

Well data: ______ pumped ______ flowing
depth ______ total
______ to water (water elev. ______)
______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments: no pH paper 6.99-7.01

pH	R	7.01		☐ paper ☐ meter
Sp. Cond.	R	805 um	(some drifting)	meter 805 μΩ
Cl		mg/l		

Other Conditions:
Contamination possibly runoff, but not certain
Sinter deposits ______
Travertine deposits ______
Geologic setting area is a travertine mound; spring is issuing from mound; may be depositing travertine
Use of water Greenhouse

Mrs. McGregor unfavorable to drilling on her property

Sketch:

McGregor Warm Spring

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 012 — Date 5/3/80

Name McG. Cold Sp. — Time 9:30 a.m.

Locaton NW ¼, NE ¼ Sec 31 — Sampler B. Cox

T12S, R41E — Weather cloudy (as in 011)

Elevation ~5050'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 13? — Ground temp. °C ______ — Air temp. °C ______

Fluid color colorless — Discharge ______ lpm couldn't determine

Fluid clarity clear

Odor none — Well data: ______ pumped ______ flowing

Gas evolving no — depth ______ total

______ to water (water elev. ______)

______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	7.10		☐ paper ☒ meter 7.10
Sp. Cond.	R	760 um		meter 760 μΩ
Cl		mg/l		

Other Conditions:

Contamination ______

Sinter deposits ______

Travertine deposits ______

Geologic setting Travertine deposits in area - Big pit in ground - no apparent deposit of travertine

Use of water drinking

Sketch:

Sample was taken from tap -- spring was in deep pit - I couldn't see much discharge -- water was stagnant

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 013 Date 5/4/80

Name Dean Burton Well Time noon-1:30 p.m.

Locaton SE ¼, NW ¼ Sec 25 Sampler B. Cox

T12S, R40E Weather warm, sunny

Elevation 4920'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 14 Ground temp. °C ____ Air temp. °C ____

Fluid color colorless
Fluid clarity clear
Odor no
Gas evolving no

Discharge ____ lpm
Well data: X pumped ____ flowing
depth 85' total
75' to water (water elev. ______)
? to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	7.30		☐ paper ☒ meter 7.30
Sp. Cond.	R	820 um		meter 820 μΩ
Cl		mg/l		

Other Conditions:
Contamination ---
Sinter deposits ----
Travertine deposits
Geologic setting In alluvium - soil

Use of water drinking water, house

Sketch:

Clay to 65', then water-bearing gravels.
Dean Burton said it was "corrosive",
and hard. Possibly depositing travertine?

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 014

Date 5/5/80

Name SMG580 - Burton Spring

Time 10:15 a.m.

Locaton SW ¼ NE ¼ Sec 26

T12S R40E

Sampler B. Cox

Weather Sunny, warm

Elevation ~5120'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 10.5 Ground temp. °C 18 Air temp. °C 21

Fluid color clear

Fluid clarity colorless

Odor no

Gas evolving no

Discharge ~900 lpm?

Well data: ______ pumped ______ flowing

depth ______ total

______ to water (water elev. ______)

______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	7.52		[ ] paper [X] meter 7.52
Sp. Cond.	R	128 um		meter
Cl		mg/l		

Other Conditions:

Contamination Possibly runoff

Sinter deposits ---

Travertine deposits ---

Geologic setting In alluvium gravels (quartzite)

Use of water house water - drinking - said to be "soft"

Sampled near spring orifice

Sketch:

Burton Spring is flowing into pool

FIELD DATA RECORD--GEOCHEMICAL SAMPLE

Sample No. 015 | Date 5/5/80

Name SMG580 - Cottonwood Creek | Time 10:57 a.m.

Locaton SE ¼, SW ¼ Sec 35 | Sampler B. Cox

T12S, R40E | Weather sunny, warm

Elevation 5120'

Sample Type: spring, well, creek, river, sinter, travertine, gas, rock, ______

Sample Data: Water temp. °C 7 Ground temp. °C 14 Air temp. °C 22

Fluid color colorless
Fluid clarity cloudy
Odor no
Gas evolving no

Discharge 9600? lpm

Well data: ______ pumped ______ flowing
depth ______ total
______ to water (water elev. ______)
______ to pump

Component--Sample type-Level meas.-Where/when--Method/comments:

pH	R	7.95		☐ paper ☒ meter 7.95
Sp. Cond.	R	220 um		meter 220 µΩ
Cl		mg/l		

Other Conditions:
Contamination
Sinter deposits
Travertine deposits
Geologic setting In alluvium

Use of water Recreation, irrigation

Sketch:

b

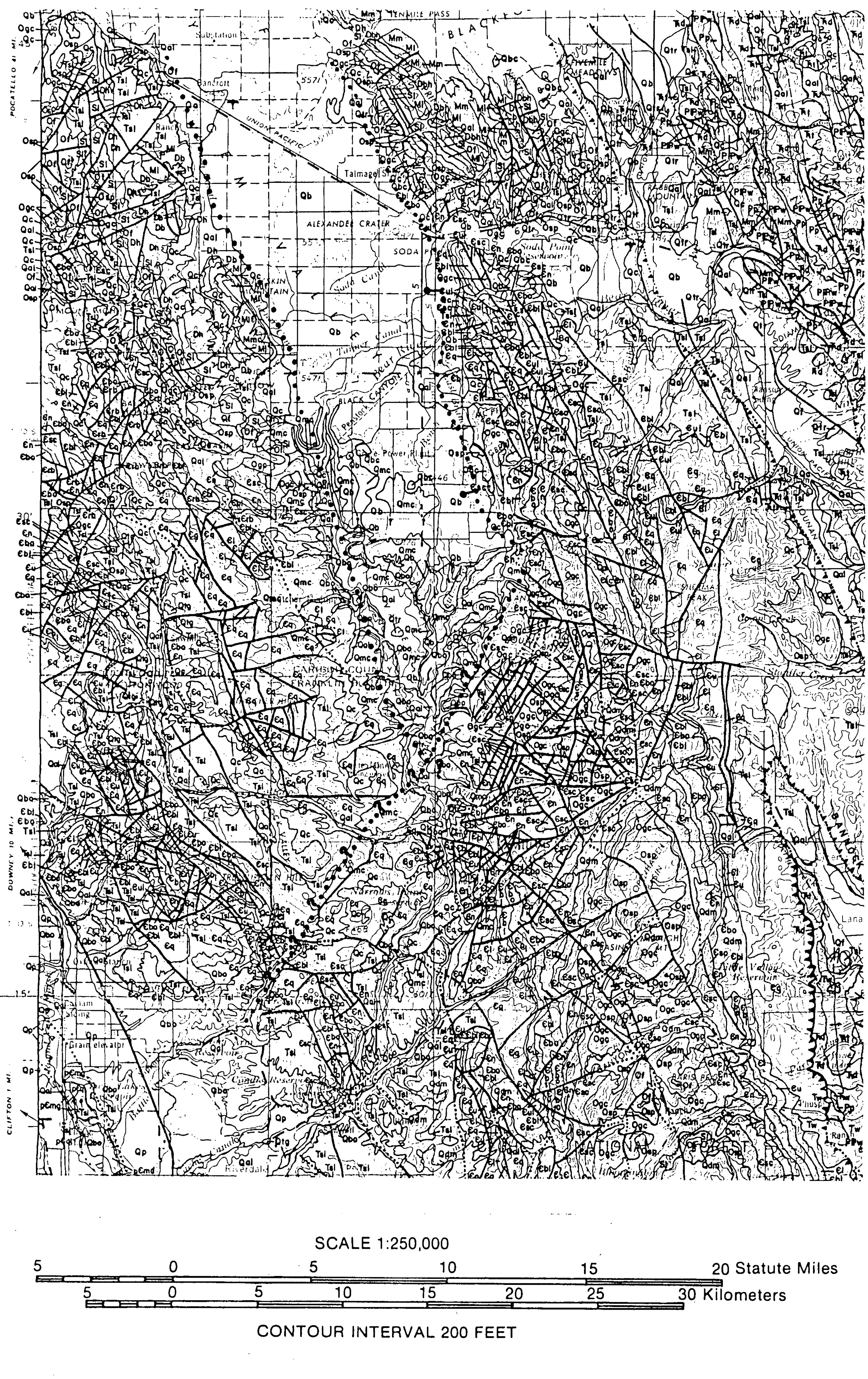


PLATE 2

Regional geologic map of the Cleveland-Maple Grove prospect area

(From Mitchell and Bennett, 1979; Bright, 1960 and unpublished regional reconnaissance)

Plate 1

STRATIGRAPHIC COLUMN IN THE CLEVELAND-MAPLE GROVE HOT SPRINGS AREA (from Bright, 1960)

PLATE 2

Regional geologic map of the Cleveland-Maple Grove prospect area

EXPLANATION

Sedimentary | **Igneous** | **Metamorphic**

CENOZOIC

Quaternary — Recent

Qal — Stream alluvium
Qls — Landslide deposits
Qc — Colluvium
Qtg — Terrace gravel
Qf — Alluvial fan deposits
Qtr — Travertine

Quaternary — Pleistocene

Qp / Qpb / Qbo — Lake Bonneville Group
- Qp — Provo Formation — *unconsolidated gravel and sand*
- Qpb — Pink silt
- Qbo — Bonneville and Alpine Formations, undifferentiated — *unconsolidated gravel and sand*

Qdm — Diamictite — *unconsolidated, unsorted detrital deposits*

Qb / Qbc / Qmc — Gentile Valley Group
- Qb — Gem Valley Basalt — *dark gray, vesicular, porphyritic, massive olivine basalt*
- Qbc — Basalt cinders
- Qmc — Main Canyon Formation — *poorly consolidated silt and marl*

QTr — Rhyolite

Tertiary — Pliocene, Eocene

Tsl — Salt Lake Formation — *tuffaceous calcareous siltstone, claystone, sandstone, and conglomerate*

Tw — Wasatch Formation — *red conglomerate and sandstone with minor limestone*

MESOZOIC

Cretaceous

Kw — Wayan Formation — *red calcareous mudstone, and red, buff, and white sandstone and conglomerate*

Kg — Gannett Group — *red mudstone and siltstone (unnamed); aphanitic gray limestone (Draney Limestone); red mudstone, and red and white conglomerate and sandstone (Bechler Conglomerate); pale gray, fine-grained limestone (Peterson Limestone); mudstone, sandstone, purplish limestone, and red conglomerate (Ephraim Conglomerate)*

Jurassic

Js / Jp / Jsp
- Js — Stump Sandstone — *thin-bedded, greenish gray, calcareous sandstone and sandy limestone*
- Jp — Preuss Sandstone — *fine-grained, red, calcareous sandstone and siltstone*
- Jsp — Stump and Preuss Sandstones, undifferentiated

Jtc — Twin Creek Limestone — *whitish-weathering, gray, shaly limestone and massive, brown, sandy limestone*

Jn — Nugget Sandstone — *massive reddish sandstone with minor shale and limestone*

Triassic

Ŧa — Ankareh Formation and associated rocks — *thin-bedded red sandstone and shale (Wood Shale Tongue of the Ankareh Formation); massive cherty limestone (Deadman Limestone); gritty or conglomeratic sandstone (Higham Grit)*

Ŧt — Thaynes Formation — *calcareous sandstone, siliceous limestone, calcareous siltstone, and argillaceous and silty limestone*

Ŧw — Woodside Shale — *olive-drab platy shale with thin beds of limestone*

Ŧd — Dinwoody Formation — *claystone, limestone, and siltstone*

PALEOZOIC

Permian

Pp — Phosphoria Formation and associated rocks — *cherty mudstone, phosphatic mudstone, chert, phosphorite, limestone, and dolomite*

Pennsylvanian

PPw — Wells Formation — *siliceous limestone, sandy limestone, dolomite, quartzite and calcareous sandstone*

Mississippian

Mm — Mission Canyon Limestone — *massive gray limestone with minor sandstone and shale*

Mmc — Monroe Canyon Limestone — *fine- to coarse-grained bioclastic limestone and finely to medium crystalline limestone*

Mlf — Little Flat Formation — *calcareous siltstone, fine-grained sandstone, and silty limestone*

Ml — Lodgepole Limestone — *thin- to medium-bedded, cherty, fine-grained to coarsely bioclastic limestone*

NOTE: Rocks shown as Mission Canyon Limestone (*originally mapped as Brazer Formation*) should be labeled as undifferentiated Mississippian. Recent work in the Georgetown Canyon area has shown that Mississippian rocks include the Lodgepole and Mission Canyon Limestones of the Madison Group and rocks equivalent to the Deseret Formation (Sando and Sandberg, 1979).

Sando, W.J. and C.A. Sandberg, 1979, Stop 7 — Georgetown Canyon Section, Idaho, *in* J.T. Dutro, Jr., editor, Carboniferous of the Northern Rocky Mountains: American Geological Institute, AGI Selected Guidebook Series No. 3.

Devonian

Dt — Three Forks Limestone — *purplish cherty shale and sandy limestone*

Db / Dh / Dbh
- Db — Beirdneau Formation — *calcitic dolomite, dolomitic limestone, silty or sandy limestone, and calcareous quartz sandstone or siltstone*
- Dh — Hyrum Dolomite — *dark blue-gray, petroliferous-smelling laminated dolomite and light gray dolomite with interbeds of limestone*
- Dbh — Beirdneau Formation and Hyrum Dolomite, undifferentiated

Dwc — Water Canyon Formation — *medium-grained, cross-bedded sandstone and very fine-grained silty dolomite*

Silurian

Sl — Laketown Dolomite — *light gray, white-weathering, finely crystalline dolomite*

Ordovician

Of — Fish Haven Dolomite — *dark gray, fetid, finely crystalline dolomite*

Osp — Swan Peak Quartzite — *fine-grained, well-sorted quartzite*

Ogc — Garden City Limestone — *dolomite and chert, grading downward into limestone with bioclastic, oolitic, and intraformational conglomeratic beds*

Cambrian

Ꞓsc — St. Charles Limestone — *dolomite, limestone, arenaceous limestone, quartzite, sandy dolomite, and arkosic quartzite*

Ꞓn — Nounan Limestone — *dolomite, silty limestone, calcareous quartz sandstone, and limestone intraformational conglomerate*

Ꞓbo — Bloomington Formation — *shaly, micaceous, green mudstone and claystone with interbeds of oolitic and aphanitic limestone, and limestone intraformational conglomerate*

Ꞓbl — Blacksmith Limestone — *limestone, arenaceous limestone, and oolitic limestone*

Ꞓu / Ꞓl / Ꞓul — Ute Limestone, Langston Formation, and equivalent strata
- Ꞓu — Ute Limestone — *thin-bedded argillaceous limestone with oolitic layers and thin shale interbeds*
- Ꞓl — Langston Formation — *light gray coarsely crystalline dolomite, thin-bedded limestone, and green mudstone*
- Ꞓul — *thin-bedded argillaceous limestone (Ute Limestone), green mudstone; light gray, coarsely crystalline dolomite, gray limestone, and green mudstone (Langston Formation), oolitic fossiliferous limestone and green mudstone*

Ꞓrb — Rocks in the Bancroft area — *mottled limestone, green shale, oolitic fossiliferous limestone, sandstone, and green quartzite*

PRECAMBRIAN

Precambrian

Ꞓq — Brigham Quartzite — *very poorly sorted, partly conglomeratic quartzite with interbedded argillite*

pꞒql — Quartzite and limestone

pꞒq — Quartzite

pꞒmd — Metadiabase

pꞒmg — Metagraywacke

pꞒs — Slate

SYMBOLS

- Contact
- Fault: dotted where concealed.
- Thrust fault: teeth on upper plate.
- Anticline
- Syncline
- •••• Regional structural trend

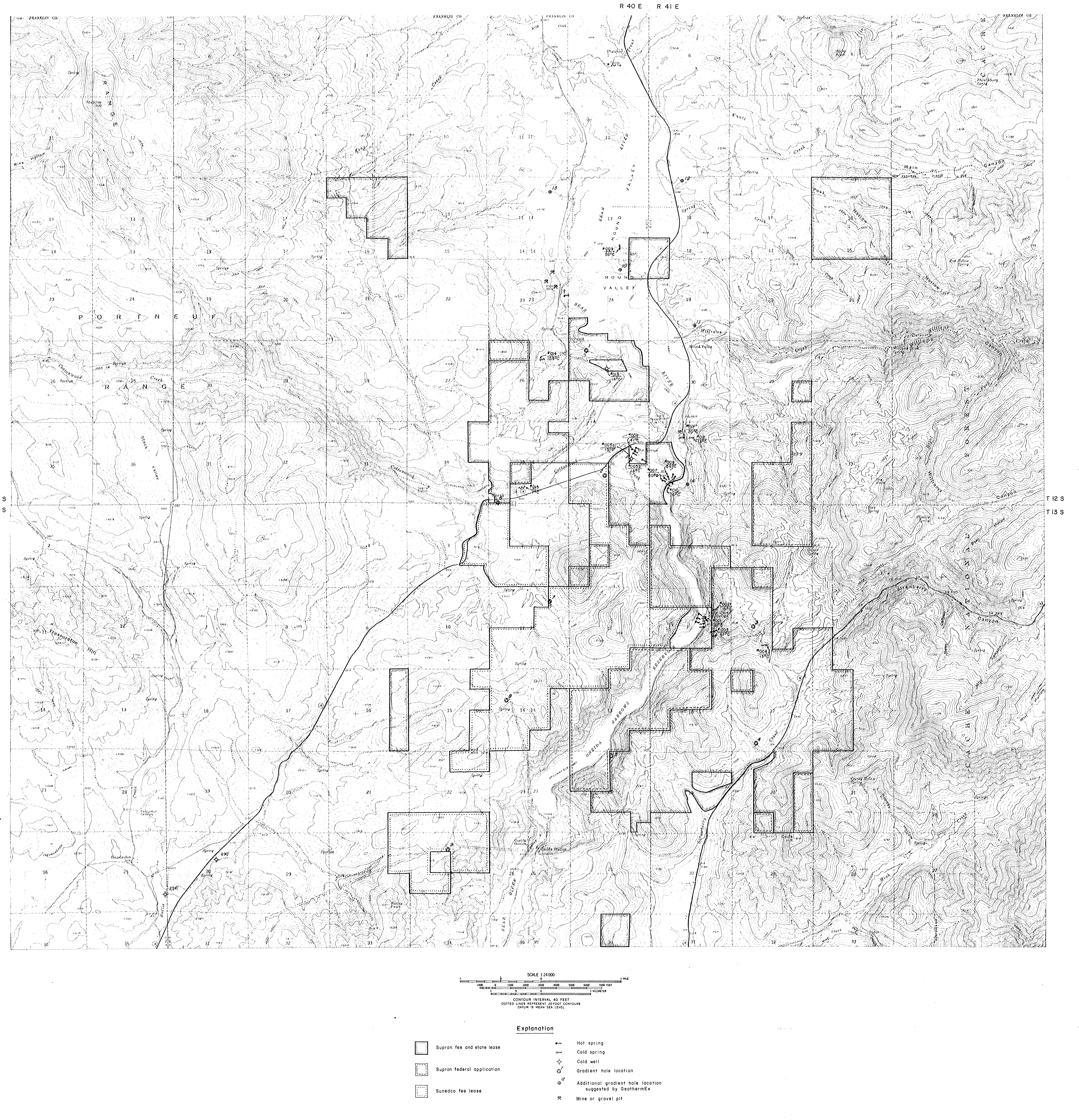


PLATE 4. Location of water samples, drillsites, and leasehold boundaries in the Cleveland-Maple Grove prospect area.